SOIL-FERTILIZER REACTIONS AND PLA SP
TO COATED AND NON-COATED CONCENTRATED SUPERPHOSPHA

By

John J. Nicholaides, III

A Dissertation Presented to the Graduate
Council of the University of Florida
in Partial Fulfillment of the Requirements
for the Degree of Doctor of Philosophy

UNIVERSITY OF FLORIDA

1973

DEDICATION

To

Gwynne and Elizabeth

ACKNOWLEDGEMENTS

The author wishes to express his sincere appreciation to Dr. John G. A. Fiskell, Chairman of the Supervisory Committee, for his valued counsel, guidance, and assistance throughout the entire course of this study, and for his valuable suggestions and excellent assistance in the preparation of this manuscript.

Appreciations are also extended to Drs. Lucian W. Zelazny, David H. Hubbell, William G. Blue, and Salvadore J. Locascio for their interest, constructive advice, participation on the Supervisory Committee, and review of this manuscript. Recognition is made of the interest, valued assistance, and participation on the Supervisory Committee of the late Dr. Curtis E. Hutton.

Gratitude is expressed to Dr. Charles F. Eno, Chairman, Soil Science Department, for awarding the NDEA Title IV Fellowship and for his words of encouragement which facilitated this study.

Special appreciation must be extended to Dr. Frank G. Martin for his useful statistical analyses of the field data.

Appreciations are extended to Dr. Raymond B. Diamond and Mr. George Slappey of the Tennessee Valley Authority for furnishing the sulfur-coated fertilizers used in this study.

To Mr. Frank Sodek and Mrs. Elma del Mundo of the Soil Science Analytical Service Laboratory and to Mr. Lex Carver and Mr. James Chichestar of the Extension Soil Testing Laboratory, appreciations are extended for their labors with certain elemental analyses. Though space

does not permit mention of individual names, thanks are in order for the aid of many others at the University of Florida and at the Agricultural Research Center at Jay, Florida.

For his excellent draftmanship of the figures in the final draft, appreciation is given to Mr. Ray Garman.

The author wishes to commend Mrs. Loan Tinsley for her excellence in typing and proofing the first draft and the final copy of this dissertation. Appreciations are also extended to Mrs. Susan Mickelberry and Mrs. Carol O'Dell for their excellent typing and proofing of the final draft of the appendix tables.

Above all, the author wishes to express the deepest gratitude to his wife, Gwynne, whose understanding, unyielding encouragement, and labor contributed immeasurably to the successful completion of this dissertation.

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Abstract of Dissertation Presented to the
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SOIL-FERTILIZER REACTIONS AND PLANT RESPONSE TO COATED AND NON-COATED CONCENTRATED SUPERPHOSPHATE

By

John J. Nicholaides, III

December, 1973

Chairman: Dr. John G. A. Fiskell
Major Department: Soil Science

Nature of soil-fertilizer reactions and associated corn response to coated and non-coated concentrated superphosphate (SCSP and CSP, respectively) were investigated in a Paleudult of high P-retention capacity. The soil used in the study was primarily Red Bay fine sandy loam [Rhodic Paleudult]. Included in the comparison of P sources for field corn were SCSP, CSP, and ordinary superphosphate (OSP). This phase of research led to an evaluation of these sources on soil-P availability and on corn responses, first to current and later to residual rates of application.

Varied laboratory studies dealt with characterization and components of P retention in this soil. Removal of organic matter and amorphous aluminosilicates had little effect on soil-P retention. However, removal of crystalline Fe and Al reduced soil-P fixation by 89%. At various P rates and equilibrium times, P sorption by Red Bay soil was

best described by use of a Gunary rearrangement of the parabolic equation with inclusion of a square-root term. Langmuir and Freundlich equations and the phosphate potential were nearly equally satisfactory for this purpose.

Phosphorus dissolution from CSP was retarded by use of S-coating; however, observation of wide variance in P released from SCSP pellets was noted in both laboratory and field studies. Though P dissolution from SCSP pellets was slower than that from CSP granules, amounts of P dissolved from these sources were equal at the end of growing season. After 10 weeks of equilibration, soil moderated acidity of leachate from both sources by one-half of a pH unit. Soil sorption of P dissolving from fertilizer granules (1,340 μg P/g soil) was comparable to P-sorption maximum described by Langmuir equation (1,560 μg P/g soil) for P rates up to 5,000 μg P/g soil. Monocalcium phosphate (MCP) in CSP and SCSP pellets was converted to less soluble P forms, primarily dicalcium phosphate (DCP), in laboratory and field trials.

Corn yield response to both initially applied and residual P was alike for CSP and SCSP sources. This indicated that P supplied to plants either in an immediately soluble form or in small, but continual, amounts of soluble P were equally effective for corn. However, with various mixtures of coated and uncoated P sources, maximum tissue-P levels and yields occurred when mixture contained 20% SCSP. Minimum tissue-P levels and yields were noted when mixture contained 80% SCSP. A residual study undertaken 2 years later revealed a reversal of these observations and indicated that SCSP was more effective as a residual P source than was CSP. No difference between use of either OSP or CSP as the uncoated source of P in the mixtures was found. Other residual studies revealed

that for both SCSP and CSP maximum yields were obtained 1 year after fertilization with 84 kg P/ha, while 168 kg P/ha were required to produce maximum yields 2 years following fertilization.

Corn yield response was alike between broadcast and band placement over a range of P rates. Corn yield response, soil-P levels, and tissue-P levels were linearly related to rate of applied P. Both available soil-P values and P content of corn ear-leaf tissue sampled at late-silking stage were linearly and curvilinearly correlated with yield; highest accounts of yield variation by the above P levels were slightly greater than 50%.

INTRODUCTION

Soluble phosphates applied to most acid soils with high sesquioxide contents are known to be rapidly changed into slightly soluble forms. Attempts at overcoming this poor efficiency or in maintaining sufficient phosphate for crops can be classed either as studies dealing with rates and placement of P fertilizer or in testing of P compounds for evidence of improved P availability to crops over that obtained by such conventional P fertilizers as concentrated superphosphate (CSP) and ordinary superphosphate (OSP). The fact that the latter sources contain monocalcium phosphate (MCP), which solubilizes upon reaction with the soil solution, is a contributing factor to the resulting P retention and to the response of crop yields to P applications. Soil testing procedures, usually chemical, are used as a measure of plant-available P content which has resulted from recent fertilization or from residual P levels present from prior fertilization.

Customarily, P fertilization of row crops in made at planting time, and hence much of the soluble P reacts with soil components prior to root development. Slow dissolution of fertilizer P, to give a more even apportionment of P over the growing season, should allow plant roots sufficient time to develop and utilize some fertilizer P prior to the formation of unavailable P compounds in the soil. Slower dissolution should allow plant roots to intercept soluble P prior to subsequent P reactions with soil components. Accordingly, to prevent rapid dissolution of fertilizers, a coating of elemental S with a wax sealant and a

microbicide was developed by the Tennessee Valley Authority for use with pelleted urea, muriate of potash, and CSP fertilizers.

For an adequate evaluation of S-coated CSP (SCSP), an agriculturally important soil with a high P-retention capacity was desired. Ultisols have been noted to be among those Florida soils with the highest P-fixation capacities (Ballard and Fiskell, 1973). Red Bay fine sandy loam [Rhodic Paleudult] is such a soil which is extensively cropped in western Florida, southeastern Alabama, and areas of Mississippi, Georgia, South Carolina, and North Carolina.

The objectives of the present studies were 1) to characterize P retention and its contributing factors in Red Bay fsl, 2) to compare SCSP, CSP, and OSP as P sources for corn in field studies, and 3) to evaluate the effects of these P treatments on soil-P availability and on compositions of corn tissue.

LITERATURE REVIEW

Factors and Mechanisms Contributing to Fertilizer Phosphate Retention by Soils

Phosphorus fixation is defined by Kardos (1967) as "the process whereby readily soluble phosphorus is changed to less soluble forms by reaction with inorganic or organic components of the soil, with the result that the phosphorus becomes restricted in its mobility in the soil and suffers a decrease in its availability to the plant." The amounts of fertilizer P which an acid soil immobilizes and the rate of that immobilization have been found to vary greatly depending on the soil's mineralogical composition, the activity of its exchangeable and crystalline Al and Fe, its amorphous aluminum hydroxides and iron oxides, and organic matter-metal cation complexes. Phosphorus fixation, retention, and immobilization are used interchangeably in the following review.

Mineralogical Reactions

By using chemically pure soil minerals, $< 2\mu$, at 26, 49, and 95C at pH values of 3, 5, and 7 in the range 0.01 to 1M P, Haseman, Brown, and Whitt (1950) showed the decreasing order in which minerals fixed P was gibbsite >> goethite > illite > kaolinite > montmorillonite. As temperature and P concentration increased and pH decreased, the authors noted that P-fixation rates increased 10-fold in montmorillonite, 8-fold in illite, and 2-fold in kaolinite. While rates of P retention by

gibbsite and goethite increased slightly with temperature, they observed that there was little effect on these rates by variation in the pH of 0.1M P additions. In addition to fixing much more P (133 mg P/g gibbsite) than any of the other minerals, gibbsite also was noted to have a faster P-retention rate (0.133 mg P/g gibbsite/hour) than for the other minerals tested. Reaction with all the minerals was described as having an initial rapid rate of reaction with P during the first 30 minutes followed by a subsequently slower rate. These two reaction rates were interpreted by the authors as being indicative of the same general type of chemical reaction. The rapid fixation, they thought, resulted from P reaction with readily available Al and Fe, while the slower fixation was believed to result from P reaction with Al and Fe which were released through decomposition of the respective minerals.

The decomposition reaction with soil minerals is similar to the P-induced decomposition of kaolinite reported by Low and Black (1948). In their work, kaolinite was purported to dissociate into Al and Si ions with P precipitating the Al, thereby disturbing the equilibrium and causing the clay to dissolve in accordance with solubility-product principles. To support their hypothesis, Low and Black (1950) studied kaolinite digestion at pH 4.9 for 2 and 3 weeks at 45C and used P solutions ranging from 0 to 3N. They reported the digestion to result in release of Si in proportion to the P fixed. They noted that the variance with time on the rate of Si release from kaolinite during P fixation indicated the existence of two types of reactions. The first and more rapid reaction was thought to be the surface replacement of the Si tetrahedra by P tetrahedra, and the second one was the P-induced decomposition of the surface compound with subsequent precipitation of an

Al-P compound.

Volcanic ash soils containing allophane and halloysite were treated by Wada (1959) with 1M ammonium phosphate solution at pH 4 and 7. After comparative test periods of 24 hours, it was found that at pH 4, P was fixed at a reaction rate of 152 mmole P/day/100 g of allophane and 11 mmole/day/100 g of halloysite. However, he reported that, after 3 weeks, a total of only 417 and 238 mmole P/100 g was retained by allophane and halloysite, respectively. He observed that the rate of reaction of allophane with P was initially quite rapid, while rate of reaction of halloysite with P was maintained at the initial rate over the 3-week period. When the pH was increased to 7 in this study, P reaction with allophane was retarded to a rate of 98 mmole/day/100 g, and for halloysite the reaction with P more than doubled to 24 mmole/day/100 g. X-ray diffraction of the P-reaction products in these samples indicated the presence of ammonium-substituted taranakites. Also noted was a shift of the 10.1A spacing observed in halloysite at pH 4 to 13.2A at pH 7 where both cases were reacted with ammonium phosphate. Since high P retention was found for halloysite at pH 7, Wada concluded that the shift to 13.2A was produced by a monolayer of $(NH_4)_2HPO_4$ being physically adsorbed between the silicate layers in the mineral.

Fox, DeDatta, and Sherman (1962) investigated P retention in seven Hawaiian soils of diverse mineralogical composition, pH, and Al activities over a 4-day period. To each of three Oxisols, two Inceptisols, an Ultisol, and a Vertisol were added 44 ppm of ^{32}P. They reported the general intensity of P fixation for the various mineralogical systems according to the average percentage of applied P which was fixed. These

percentages were as follows: 99.5% for amorphous hydrate oxides of Fe and Al > 98.5% for crystalline gibbsite-goethite > 98.0% for kaolinite > 92.5% for 2:1 lattice layer clays. In a comparison of the relative effect on P retention of active Al compared to mineralogical composition, these workers found that even when active Al was reduced to zero by liming, soils with different clay mineralogy differed as much as 40 times in P retention. They concluded that the apparent overriding factor in P retention by these Hawaiian soils was differences in their mineralogy.

Hall and Baker (1971) examined P fixation in montmorillonite and vermiculite, each having a CEC of 116 meq/100 g. They used Al additions from 0-90 meq/100 g, P additions in the range from 0-1600 ppm, and a pH range from 4-7. In this experiment, they found that for all Al and P rates at pH 4, both clay minerals fixed 67% of the added P, and that when the pH was increased to 7, the percentage of P retained by montmorillonite increased to 82%, whereas that held by vermiculite dropped to 61%. They also reported that X-ray diffraction of vermiculite at 300C showed stable 14A spacings indicating interlayered stable Al polymers, the edges of which were postulated to be Al-P reaction sites. Since montmorillonite, in their studies, did not exhibit these stable interlayers, the authors contended that the Al-P reaction sites were a separate solid phase in montmorillonite. Consequently, the authors postulated that, for soils with clays reacting like the vermiculite of their study, lime addition prior to P application will reduce P fixation by reducing the specific surface of reactive Al through stable interlayer Al polymer formation, thereby reducing Al surfaces available for P reactions. Similarly, with soils containing clays having properties similar to the montmorillonite they studied, liming would increase P

retention.

Aluminum and Iron

Numerous workers have confirmed the work of Chang and Jackson (1958) which contended that, when fertilizer P is added to an acid soil, some form of calcium phosphate (Ca-P) is the initial reaction product, but this form soon changes to aluminum phosphate forms (Al-P) and, with further time, reverts to some form of iron phosphate (Fe-P). Unless so stated in the ensuing review, the phosphate forms are by definition those extracted by Chang and Jackson fractionation procedure (1957), with the Fife modification (1962). By this terminology, Al-P is obtained by extraction with 0.5N NH_4F at pH 8.3, Fe-P is found by extraction with 0.1N NaOH for 24 hours, and Ca-P is that removed subsequently by 0.5N H_2SO_4. Yuan, Robertson, and Neller (1960) noted in laboratory studies that when 50 and 100 ppm P were applied to Red Bay fine sandy loam [Rhodic Paleudult], 44.6 and 61.2%, respectively, of the applied P were in the Al-P form, while 49.1 and 34.3% of the applied P, correspondingly, were in the Fe-P form. Using the above soil and another Paleudult, these workers also noted that as P rates were changed from 0-1000 ppm, the ratio of Al-P: Fe-P was also increased from 4:6 to 7:1.

By adding 200 ppm P to six different Taiwan soils having a pH range from 5.3 to 7.5 and maintained at field-moisture levels for 3 days, Chang and Chu (1961) found that 56% of added P was fixed as Al-P, 23% as Fe-P, and 7% as Ca-P. After 100 days under the same conditions, they noted Fe-P increased to 43% of the total recovered P, while Al-P and Ca-P decreased to 44 and 5%, respectively. By adding 200 ppm to each of these soils and equilibrating the suspensions for 3 hours, the authors found a net increase of 32, 39, and 4% in the P recovered as

Al-P, Fe-P, and Ca-P, respectively. From these data, they suggested that the first stage of fixation of added P by various cations occurs on the solid phase surface with which P comes in contact, and that the relative amounts and kinds of P formed depended on the specific surface area of solid phases providing Al, Fe, and Ca for the reactions.

Having based P-fixing capacity of four acid Ohio soils on the ability of a soil to retain 26 ppm of soluble P against 0.03N NH_4F in 0.025N HCl extraction, Volk and McLean (1963) defined low and high P-fixing soils as those retaining 25% or less and 50% or more of the applied P, respectively. These workers found that in soils of low-fixation capacity, most of the applied P was in the Al-P form, while in soils with high-P fixation, most of the applied P was found in the Fe-P form. When a high P-fixing soil was limed, the percentage of the applied P increased from 30 to 50% as Al-P percentage decreased from 70 to 50%

In a study on Lakeland fine sand [Typic Quartzipsamment] where 800 lbs/acre of triple superphosphate (TSP) were applied in 18 application with and without lime over a 6-year period, Fiskell and Spencer (1964) recovered the primary form of applied P as Al-P, with lesser amounts of dicalcium phosphate dihydrate (DCPD), Fe-P, and octacalcium phosphate (OCP) or hydroxyapatite (HAp). They found, even with high liming rates, that 50% of the applied P was recovered as Al-P, while the remainder was in the form of Fe-P and Ca-P. They reported that both tricalcium phosphate (TCP) and DCPD which resulted from the TSP applications to the soil were dissolved by 1N NH_4OAc at pH 4.8 used as the first step in the sequential extractions. They stated that use of 1N NH_4Cl as recommended in the sequence by Chang and Jackson (1957) might result in

some Ca-P forms being recovered in the Al-P fraction.

After initial applications of 343, 685, and 1,371 kg P/ha, Shelton and Coleman (1968) analyzed samples taken from a Georgeville soil [Typic Hapludult] over an 8-year period. This soil was high in kaolinite, with lesser amounts of 2:1 to 2:2 lattice clay minerals, a small amount of gibbsite and about 5% free-iron oxide. Its initial pH of 5.3 had been increased to 6.0 with liming. Over the 8-year period, they found that a marked decrease of Al-P occurred, while Fe-P increased. At the lowest P level, Al-P/Fe-P decreased from 1.4 to 0.2. Reductant soluble-P, as defined in the method by Chang and Jackson (1957), was detected after 3 and 5 years at the two higher rates of P fertilization.

This same pattern of Al-P eventual reversion to Fe-P was noted by Appelt and Schalscha (1970) in volcanic ash soils of Southern Chile. In evaluating P-retention capacity of 14 Costa Rican soils, Fassbender (1968) found that young volcanic-ash-derived soils, Andepts or Inceptisols, exhibited a larger P-fixation capacity than did the Oxisols, many of which are Ultisols.

Exchangeable and crystalline aluminum and iron

Coleman, Thorup, and Jackson (1960) investigated P sorption on 60 sub-soil samples of six Typic Hapuludults from the North Carolina Piedmont. Aluminum exchangeable by 1N KCl extraction was found to be correlated ($r = 0.838$) with P sorption. These researchers found that salt leaching of the exchangeable Al reduced P sorption in these soils having appreciable exchangeable Al. However, salt leaching of clayey, kaolinitic soils, such as Cecil, which contained little exchangeable Al (< 1 meq/100 g), but large quantities of Fe and Al oxides and hydroxides, resulted in little decrease in P sorption. These workers

also found P binding in soils to be at a maximum near pH 7 in salt-free Al systems and near a maximum at pH 4 in presence of Cl salts which displaced Al from exchange sites. The phosphate-binding reactions, they suggested, involved exchangeable Al and led to the formation of a crystalline substance similar to variscite.

A similarly high correlation, r = 0.925, between P sorption and exchangeable and citric acid-soluble Al was obtained by Franklin and Reisenauer (1960) on 14 acid soils which they classed as Latosols, Podzols, Alluvial, Humic-gley, Sierozem, and Prairie soils. They reported that citrate acid-extractable Al was 160 times more active in P sorption in these soils than was citrate acid-extractable Fe. In contrast to the work presented previously on effects of the soil mineralogy on P retention, these authors could find no relationship of P sorption to either the mineralogy or content of clay in any of the soils used.

In 11 Florida Ultisols, correlations between P retention and amounts of Al and Fe extracted by various reagents were reported by Yuan and Breland (1969). They stated that P retention was more highly correlated (r = 0.96) with citrate- dithionite-bicarbonate (CDB)-extractable Al plus Fe than with Al and Fe extractable by reagents such as 1N NH_4OAc at pH 4.8, 0.1N HCl, 0.2M $(NH_4)_2C_2O_4$ at pH 3.0, or 0.5N NaOH. Both P retention and extractable Al correlations, they found, were highest (r = 0.90) for CDB-extractable Al which is purported to extract much of the crystalline Al. In their studies, P retention and extractable Fe were correlated (r = 0.92) for Fe extracted by CDB reagent and were similar to the relationship of P retention and oxalate-extractable Fe (r = 0.92), wherein the latter reagent is useful in removal of amorphous

Fe forms. They also reported that correlation coefficients between P retention and Al, Fe, and Al plus Fe extracted by hot 0.5N NaOH were 0.81, 0.87, and 0.82, respectively.

Velez and Blue (1971) recorded P sorption in a Rhodic Paleudult (Red Bay fsl) from Florida and a tropical alluvial Entisol from Costa Rica that received three treatments: no pretreatment, oxalate extracted, and CDB extracted. After addition of 5000 ppm P, P sorption in the Paleudult for the above treatments was 50.1, 47.5, and 27.6% of the applied P, respectively; the P sorption in the Entisol after the same treatments was 96.0, 47.4, and 50.6%, respectively. From their data, they concluded that P sorption in the Paleudult resulted primarily from precipitation with crystalline Al and Fe, while in the Entisol P retention was controlled by the amorphorus Al present.

Amorphous aluminum hydroxides and iron oxides

In agreement with studies by Coleman et al. (1960) and Franklin and Reisenauer (1960), Syers et al. (1971) found P sorption to be correlated ($r = 0.84$) with exchangeable Al in the surface samples of 15 Brazilian soils classified as Ultisols and Oxisols. These soils retained from 60 to 490 μg P/g from the addition of 500 μg P/g soil. However, in these soils, removal of exchangeable Al produced only a small decrease in the amount of P sorbed. This response was quite similar to that of Typic Hapludults reported by Coleman et al. (1960) which also had little exchangeable Al, but large quantities of Fe and Al present as oxides and hydroxides. Reeve and Sumner (1970) could find no apparent relationship between exchangeable Al and P-fixation capacity of eight Oxisols in Natal. Since in these studies these workers did not determine the Al and Fe oxides and hydroxides, no

comparison could be made between their work and that of Coleman et al. (1960).

Using 10 Podzols from Scotland, Williams (1960) reported that acid oxalate-extractable Al was highly correlated ($r = 0.88$) with P sorption. Oxalate-extractable Fe also was correlated ($r = 0.68$) with P retention, but addition of a term accounting for Fe in the equation never did improve the estimation of P sorption accounted for by Al alone. Bromfield (1964) used biological reduction proposed by Bromfield and Williams (1963) and 0.05N HCl to remove Fe and Al from three acid Scottish soils with P-retention capacities varying from 3.8 to 7.5 mmole P/100 g soil. In his investigations, as Al was left unchanged, P sorption was observed to decrease slightly by 1.1 mmole as the first 11 mmole Fe/100 g soil were removed; as the next 10 mmole Fe were removed, P sorption was found to remain constant. However, as Al was removed from the same soils by acid leachings, P sorption was decreased to as much as 60% of the initial value, regardless of whether Fe was removed or left intact.

For the majority of 47 acid soils from Australia, Bromfield (1965) found Al extracted by ammonium oxalate at pH 3.2 to correlate better ($r = 0.98$) with P sorption than oxalate-extractable Fe ($r = 0.79$). However, he stated that the relative contributions of the amorphous Al and Fe to P sorption could not be accurately assessed due to the positive correlations ($r = 0.79$) between extractable Al and Fe.

Using 12 acid soils of varying Fe oxide contents, including the A_1 and B_2 horizons of Cecil [Typic Hapludult], Ramulu, Pratt, and Page (1967) noticed P retention was significantly correlated to both CDB-extractable Fe ($r = 0.77$) and oxalate-extractable Fe ($r = 0.95$). These

authors showed that, at the same level of CDB-extractable Fe, soils with only kaolinite as the dominant clay mineral fixed more P than soils with both kaolinite and vermiculite. The inference drawn from their work was that there was a finite amount of Fe present in those soils with vermiculite that was CDB-extractable, but which was not active in P retention. They postulated that Fe-hydroxy polymers form in the interlayer spaces of vermiculite and that these Fe polymers were not active in P retention, but were CDB-extractable. Since they did not find that oxalate extraction removed Fe from vermiculite interlayers, it was concluded that oxalate provided a more quantitative means of determining the relationship between Fe oxides and P retention than did CDB treatment. However, in the Cecil A_1 sample which contained gibbsite and had an oxalate-Fe/CDB-Fe ratio of 0.4, it was observed that more P (5.86 mg/g) was fixed than in the other soils with ratios of twice this magnitude. However, Ramulu et al. (1967) explained such anomolous behavior by stating that perhaps some crystalline Fe of this soil entered into the P-retention mechanism.

Another probable occurrence is that the gibbsite was responsible for the additional P retention (Haseman et al., 1950). Syers et al. (1971) found CDB also removed almost equal quantities of Al (1.1 to 19 mmole/100 g) and Fe (1.4 to 41 mmole/100 g) from the 15 Brazilian Oxisols and Ultisols studied. Although Ramulu et al. (1967) had corrected for 1N KCl-extractable Al in their correlations between Fe and P retention, they felt that in the presence of high amounts of free-iron oxides, it was reasonable to assume that fixed P was mainly due to the iron oxides. However, the contributions to P retention by Al which was CDB-extractable were essentially ignored by Ramulu et al. (1967).

Syers et al. (1971) reported that oxalate removal of amorphous Fe and Al components from the Brazilian Oxisols and Ultisols, when compared to untreated samples, reduced P sorption by 19 to 100%, while CDB removal of Fe and Al changed P sorption in a range from 12% increase to 84% decrease. Their observation was that the amount of the added P which was sorbed by untreated samples was better correlated with oxalate-Al ($r = 0.78$) than with oxalate Fe ($r = 0.47$). These workers also suggested that in P sorption by these untreated soils, amorphous Al components were more active per unit weight than were amorphous Fe components.

The results of these studies by Ramulu et al. (1967) and Syers et al. (1971) give credence to the contention of Hsu (1965) that surface-reactive amorphous aluminum hydroxides and iron oxides, rather than crystalline Al and Fe, dominate P retention in soils. Hsu (1964) reasoned that since the activity of Al^{3+} or Fe^{3+} in solution is limited by pH (being negligible above pH 5), and since no such limitation is imposed on the surface reactivity of amorphous aluminum hydroxides and iron oxides, evidence for P sorption being a surface reaction rather than precipitation could be obtained by adding dilute P solutions with pH adjusted to 7. Accordingly, he found that when solutions containing 0-60 ppm P at pH 7 were added to a slightly acid Elstow clay loam (pH 6.4), two fixation reactions operated at different rates. This author postulated that the more rapid reaction was due to surface adsorption of P on amorphous aluminum hydroxides and iron oxides present in the soil, while the much slower reaction was believed to be due to a similar surface adsorption on secondary amorphous hydroxide and oxide surfaces that developed during ageing for one year. In a hypothetical

consideration of P retention work, Hsu (1965, p. 403) concluded:

> 1. In principle, precipitation and adsorption result from the same chemical force. Whether precipitation or adsorption occurs is dependent on the form of aluminum and/or iron present at the moment of reaction. In common soils, because of the effect of pH, surface-reactive amorphous aluminum hydroxides and iron oxides dominate the process of phosphate fixation rather than Al^{3+} and Fe^{3+} in solution.
>
> 2. The concentration of phosphate in solution is determined by the sum of the activities of all forms of aluminum and iron; thus, the study of the development of the activity of phosphate-fixing cations, particularly amorphous aluminum hydroxides and iron oxides, is a more fundamental approach than is the study of the solubility of phosphate compounds.

The above conclusions at least partially rejected the phosphate phase equilibria study of Lindsay and Moreno (1960) in which activity isotherms for the variscite, $AlPO_4 \cdot 2H_2O$, and strengite, $FePO_4 \cdot 2H_2O$, among others, were represented on a solubility diagram. A function of the phosphate activity in solution was plotted against pH on this solubility diagram. By assuming the respective Al^{3+} and Fe^{3+} activities in soils to be limited by the solubilities of gibbsite and goethite, the authors were able to assess the relative stabilities of variscite and strengite and to predict their transformations in soils after fertilizer or lime applications.

However, Hsu (1965) did not take into account the finding of Lindsay, Frazier, and Stephenson (1962) that in the microenvironment around a particle of monocalcium phosphate (MCP) derived from fertilizer, such as concentrated superphosphate (CSP), an extremely low pH of 1.5 occurred within an hour after application to the soil. The resulting metastable triplepoint solution (MTSP) was defined by the authors as the solution

saturated with respect to $Ca(H_2PO_4)_2 \cdot H_2O$ and $CaHPO_4 \cdot 2H_2O$. They noted that after 15 minutes, MTSP had dissolved from the contacts with Hartsells fsl [Typic Hapludult] 40 and 138 mmole/liter of Fe and Al, respectively. After 3 days, they noted that the pH of the filtrate had risen from 1.8 to 2.1, and that the Fe and Al compositions of that filtrate were 53 and 322 mmole/liter, respectively. Filtrates obtained during the 3-day reaction period, upon standing, yielded precipitates identified as colloidal ferric aluminum phosphate, $(Fe,Al,X)PO_4 \cdot nH_2O$ of indefinite composition, where X is any cation other than Fe and Al, and n is a variable. At the low pH present in the microenvironment of the P fertilizer, Fe^{3+} and Al^{3+} were active, according to Lindsay and Moreno (1960), and came into solution, thereby precipitating P. This might be contrasted with the laboratory study of Hsu (1964) in which P added at pH of 7 to soil was retained in a situation less likely to simulate actual field conditions which made it appear that amorphous aluminum hydroxides and iron oxides were responsible for P retention. Under field conditions, Al^{3+} and Fe^{3+} resulting from fertilization acidity could also enter into P sorption by soils.

Organic Matter Complexes

As previously presented, Williams (1960) found P retention in 10 Podzols from Scotland to depend primarily on oxalate-Al. In all soils in these tests, he found P retention to be highly correlated with easily oxidizable soil C ($r = 0.77$-0.89). After finding high correlations between this C and Al ($r = 0.54$-0.89), and to a lower degree between C and Fe ($r = 0.15$-0.59), the author concluded that humate-Al and possibly humate-Fe complexes also entered into P retention of the soils. Weir and Soper (1963) studied P interaction with humic acid (HA)-Fe complexes.

They found that, while ferric iron usually precipitated as ferric hydroxide above pH 2.3, in the presence of HA considerable amounts of Fe were active in solution. They demonstrated that this Fe complexed with HA and sorbed considerable added P. When the authors subjected the HA-Fe-P complex to shaking with a hydroxide-exchange resin, the complex was able to retain 38% of the P. From 90 to 100% of this P was exchangeable with ^{32}P.

In 24 acid New Brunswick soils, Saini and MacLean (1965) found that organic matter (OM), as determined by the method of Walkley-Black (1934), was related to P retention by a correlation coefficient of 0.60. Also, Al extracted at 50C with sodium hydrosulphite in citrate buffer at pH 4.75 had been found to be highly correlated ($r = 0.91$) with P retention and with OM content ($r = 0.79$) in these soils. The authors suggested that part, but not all, of the active Al in these soils was associated with OM in the form of P-retaining complexes.

On a wide variety of 50 New Zealand topsoils ranging in their classification from Brown-Gray Earths to Podzols, Saunders (1965) found soil OM was not directly concerned with P retention; however, a close correlation ($r = 0.70$) existed between OM and oxalate-extractable Al and Fe. The author postulated that the OM-Al-Fe complex was a gel complex which could sorb P. It was probable, he stated, that the amorphous Al and Fe extracted by the oxalate were derived from this gel and that this gel was the major site for P retention in the soils he investigated.

Fox and Kamprath (1971) found added P to be readily leached from a muck soil possessing only 0.02 meq/100 g of exchangeable Al. At the low P rate of 25 kg/ha, all of the applied P was removed from this muck.

At a rate of 100 kg P/ha, the small amount of P not recovered by leachings was considered to be held by metal cations complexed by the OM.

Measurement of Phosphate Availability in Soils

Although applied P is retained by various Al and Fe compounds in acid soils, some of this fixed P has proven to be available to plants. Plant availability of soil P has generally been dependent on the form in which P is held in the soil. The availability of P from synthetic amorphous and crystalline Al-P compounds was investigated by Juo and Ellis (1968) using sundangrass as the indicator crop in quartz sand cultures. Their study indicated that relative availability of P from the compounds studied was strengite < variscite <<< colloidal Fe-P ≈ colloidal Al-P. The authors found surface area of the above compounds in the order listed to be 1.98, 24.9, 27.5, and 10.5 m^2/g, respectively. However, it was noted that crystallization of the colloidal Fe-P to strengite was essentially complete after 12 hours of digestion at 105C, while crystallization of amorphous Al-P to variscite required 40 days of digestion at this temperature. At 35C, amorphous Fe-P was observed to crystallize within 9 months, while Al-P was found to remain amorphous over this period. These results indicated to the authors that degree of crystallinity seemed to be more important than surface area in determining relative availability of Al-P and Fe-P compounds.

The above results were in agreement with previous work by Taylor, Gurney, and Lindsay (1960), Lindsay and Dement (1961), and Taylor et al. (1963). These three greenhouse experiments compared the availability to corn of various Al-P and Fe-P compounds on a Hartsells fsl [Typic Hapludult] using monocalcium phosphate (MCP) as a reference P source.

Total P uptake by three successive corn crops from colloidal Al-P was found by Taylor et al. (1960) to be much greater than that from colloidal Fe-P at a soil of pH 4.8. These authors observed during the three successive crops that P uptake from colloidal Al-P was essentially unchanged, while that from colloidal Fe-P decreased drastically after the first crop. These findings were interpreted by Juo and Ellis (1968) to be due to Al-P remaining colloidal during the cropping period, while the colloidal Fe-P crystallized rapidly. Although strengite was found to be completely unavailable in Hartsells fsl at pH 4.9, colloidal Fe-P was 78% as available as was MCP (Lindsay and Dement, 1961). With liming to pH 6.5, colloidal Fe-P was noted to be as available as MCP. In addition to colloidal Al-P and Fe-P compounds, calcium ferric phosphate ($H_4CaFe_2(PO_4)_4 \cdot 5H_2O$), potassium taranakite ($H_6K_3Al_5(PO_4)_8 \cdot 18H_2O$), and ammonium taranakite, at rates of 200 and 1000 mg P/pot, were found to be relatively available P sources for corn when applied to the above acid Hapludult (Taylor et al., 1960; Taylor et al., 1963).

On acid soils, the Al-P fraction, as determined by 0.5N NH_4F, at pH 8.3, has been reported by many workers to be more closely correlated with plant-available P than was the Fe-P fraction removed by 0.1N NaOH extraction. Smith (1965) observed that Al-P was the main source of P available to wheat grown in a slightly acid Red-Brown Earth. However, in the absence of wheat, this Al-P which was taken up by wheat in other pots was found to be converted to Fe-P compounds. From this he concluded that the plant probably was taking up some soluble P from the Al-P fraction which in the absence of plant roots would be precipitated as Fe-P. Payne and Hanna (1965) found that P content of millet tops grown on three acid Podzols of low, medium, and high P-retention capacity was

chiefly correlated with the Al-P fraction (r = 0.56). Using 12 soils varying from 28 to 72% fixation of soluble P against 0.03N NH_4F in 0.1N HCl, Lavery and McLean (1961) found the lower P-fixing soil tied up 2.5 times as much P in the Al-P fraction as in the Fe-P fraction. In their work, higher P-fixing soils were observed to have twice as much P in the Fe-P fraction as in the Al-P fraction. These workers stated that these results suggested P from the Al-P fraction would be more plant available than that from Fe-P fractions.

Indices for Phosphate Availability

Phosphorus availability and retention in soils have been measured by a variety of methods. Foremost among these is the use of chemical extractants designed to indicate levels of P available to plants. Since most work on acid soils indicates Al-P to be the fraction most closely correlated with plant growth, a selective extractant for primarily Al-P would seem to be desirable. Extractants which have been used to estimate plant-available P are given in Table 1.

For purpose of brevity, the methods listed in Table 1 will be referred to as reagents 1-12 and, unless otherwise stated, the first soil to solution ratio and shaking time are understood to have been used. Comparing P extracted from 74 U.S. soils by reagents 1, 2, 5, and 9, Fitts (1956) reported reagent 1 to be best for determining available P (r = 0.70) and least affected by soil pH or cation exchange capacity to anion-exchange capacity ratio. When the soils were limited to those with pH less than 6.1, the correlation coefficient for reagent 1 increased to 0.80. Similar results were found by C. F. Griffin (1971) after 13 acid Connecticut soils were limed. In this work, extractable P was determined by reagents 1, 5 (15 minutes' shaking time) and 9 for

Table 1. Some chemical methods used for estimation of plant-available soil P

Reagent no.	Extracting solution	pH	Soil/solution w/v	Shaking time, min	Reference
1	0.03N NH_4F + 0.025N HCl	2.7	1:10 & 1:50 1:10 & 1:50	1 5	Bray and Kurtz (1945)
2	0.03N NH_4F + 0.1N HCl	1.5	1:10 & 1:50 1:10 & 1:50	1 5	Bray and Kurtz (1945)
3	0.002N H_2SO_4 buffered with $(NH_4)_2SO_4$	3.0	1:200	30	Truog (1930)
4	0.5M $NaHCO_3$	8.5	1:20 1:50	30 240	Olsen et al. (1954)
5	0.5N CH_3COOH buffered with CH_3COONa	4.8	1:5	30	Morgan (1941)
6	0.1N $CH_3CH(OH)COONH_4$ in 0.4N CH_3COOH	3.7	1:20	240	Egner, Riehm, and Domingo (1960)
7	2.5% CH_3COOH	2.6	1:50	120	Williams and Stewart (1941)
8	0.2N H_2SO_4	0.8	1:50	990	Bondorff (1952)
9	0.05N HCl + 0.025N H_2SO_4	1.3	1:7	5	Fitts (1956)
10	1N CH_3COONH_4	4.8	1:10	30	McLean et al. (1958)
11	1N NH_4Cl	3.9	1:50	30	Chang and Jackson (1957)
12	0.5N NH_4F	8.3	1:50	960	Fife (1962)

each soil at five liming levels, giving a pH range from 5.3 to 7.7. It was found that changes in extractable P by reagent 1 were less affected by soil differences than P extracted by the other methods. On virgin Red Bay fsl [Rhodic Paleudult] Robertson and Hutton (1953) found that reagent 3 (1:40 soil to solution ratio) removed an amount of P representative of plant-available P. However, they report that when residual P exceeded 20 and 80 kg P/ha, reagents 1 and 2 gave a better measure of available P than other methods tested. In a detailed comparison of reagents 1-7 at all the soil to solution ratios and shaking times listed in Table 1, Sherrell (1970) deemed reagents 1 and 2 at a 1:10 soil to solution ratio to be the most rapid, practical, and accurate for available P analysis of 16 varied New Zealand soils. Minor alterations in time of shaking were shown in this study to have little effect on P extracted by reagents 1 and 2. Phosphorus extracted by reagent 1 was found by Sherrell (1970) and Payne and Hanna (1965) to be significantly correlated for both extraction times with the Al-P fractions in the soils, while P extracted by reagent 2 was correlated with Ca-P. However, on five Minnesota soils with pH from 5.9 to 7.5 and textures ranging from loamy sand to clay, reagents 1 and 2 were reported by Chai and Caldwell (1959) to be very closely correlated with Al-P ($r = 0.96$ and 0.98) and with Fe-P ($r = 0.93$ and 0.89), but not with Ca-P fractions as determined by the method of Chang and Jackson (1957). Phosphorus extracted by reagent 2 was noted by Sherrell (1970) to be correlated with white clover yield after P fertilization ($r = 0.89$), with yield without P additions ($r = 0.87$) and with P uptake ($r = 0.79$). In an evaluation of P extracted by reagents 1, 2 (both 1:7 soil to solution ratio), 3, 4 (1:25 ratio), 5 (15 minutes), 6, and 8 from acid, volcanic-

derived soils of the Windward Islands, Walmsley, Twyford, and Cornforth (1971) reported that results by reagent 2 correctly predicted banana-yield response to P fertilization for 85% of the tests.

However, the reagents containing NH_4F (reagents 1, 2, and 12) have been shown to dissolve compounds other than Al-P. Bromfield (1967) reported that another researcher found DCP and TCP to be "extensively dissolved" by reagent 12, although no data were given. Extraction with reagent 12 was reported by Bromfield (1967) to release primarily Al-P and variable amounts of Fe-P and Ca-P from 14 New Zealand acid surface soils having wide P-sorption capacities and Fe and Al contents. Of the P in the various compounds, he noted that reagent 12 dissolved 96% of DCP, 88% of TCP, and 23% of the P residue from water-leached SP. Since appreciable amounts of DCP and anhydrous DCP were shown to be formed in the vicinity of a SP granule (Lindsay et al., 1962), Bromfield (1967) suggested that reagent 12 can clearly overestimate the Al-P fraction in a fertilized soil. Blue (1970) used reagent 12 at pH 8.2 and found 14 and 53% of P in TCP were dissolved after extraction times of 1 and 96 hours, respectively. In the above study, reagent 11 was noted to dissolve 34% P from TCP after 1 hour.

On 29 acid to neutral surface soils from California, Pratt and Garber (1964) found that P extracted by reagents 2 and 11 were correlated ($r = 0.82$), as were those of reagents 2 and 11 ($r = 0.65$). Using four Mollisols and two Alfisols which differed in pH and P fertilization, Tandon, Motto, and Kurtz (1967) compared elements extracted by reagent 1 and those extracted by each of its components. In the acid soils of their study, they found that P extracted by reagent 1 exceeded the sum of P removed separately by each component. Neither P extracted by

reagent 1 nor by 0.03N NH_4F was correlated with soil pH, Al, Fe, Ca, Mg, Mn, or Si levels. Reagent 1 was found by these workers to extract an average of 21 ppm P, 850 ppm Al, 575 ppm Ca, 200 ppm Mg, and 65 ppm Mn from these soils. However, when these soils were first treated with reagent 12, the average amounts of P, Al, Ca, Mg, and Mn subsequently extracted by reagent 1 were 7, 14, 25, 20, and 15 ppm, respectively.

Phosphate Potential

Another index of soil-P availability used in the literature is phosphate potential, defined as $\frac{1}{2}pCa + pH_2PO_4$ by Aslyng (1954) and Schofield (1955). Phosphate potential, reported in some literature as Pot^{sp} and termed herein as PP, is a measure of the ease of P removal from soil. Quantity (Q) and intensity (I) were defined by Williams (1967) as the amounts of P sorbed by a soil and the P concentration remaining in solution, respectively. In his study, the rate at which P moved from sorbed (Q) to soluble (I) form was denoted capacity (C). Beckett and White (1964) termed the Q/I relation as $\delta Q/\delta I$ and called it potential buffering capacity, PCB. Such definitions are consistent with those employed herein.

Ramamoorthy and Subramanian (1960) compared correlations of crop response with P removed by reagents 1 and 4, P sorption, desorption and anion-exchange capacities, PP, and their own equilibrium PP (EPP), using a wide variety of paddy Indian soils which varied in pH from 5.2 to 7.4. Equilibrium PP was obtained by equilibrating soil samples with small increments of MCP solution and determining at which level of MCP was PP found to remain constant. A higher correlation for crop responses to P fertilization on the 10 soils was found with EPP ($r = 0.77$) than with any other method tested. Values for PP by the Schofield method

were found to range from 6.87 to 8.42, while those for EPP ranged from 7.43 to 8.15. The relationship between PP values and P content of cotton plants from 13 fields of a red clay loam in Uganda was reported by Le Mare (1960) to be very close (r = 0.88). The range of values for $\frac{1}{2}pCa + pH_2PO_4$ in this samples was 6.59 to 8.15. Using 26 Rhodesian and 4 Zambian soils which were derived from acid and basic igneous and sedimentary rocks, Salmon (1966) found Q/I in these acid soils to be better correlated with percent P taken up by grass (r = 0.93) than was either Q (r = 0.84) or I (r = 0.89). The Q/I relationship was reported to have accounted for 87% of the variation in P content of grass in this investigation.

Taylor and Gurney (1965c) added $CaCO_3$, sufficient to provide from 0 to 200% of the CEC, to 5 acid Ultisols and examined the resulting PP and resin-extractable P values. They reported that, while PP showed little change on addition of excess $CaCO_3$, amounts of resin-extractable P increased with pH. The authors inferred from the results that a greater quantity of P was adsorbed in a more readily removable form in limed soil than in unlimed soil. White and Haydock (1967) evaluated P availability as measured by PP against that by reagents 3, 4, and 5 on 15 soils covering a range of P availabilities which they classified as deficient to adequate. By adding $CaCO_3$ where required, the pH of each soil was raised to a range of 5.5-6.0. Using Phaseolus lathyroides L. as an indicator crop on acid soils of variable Ca status and with high Al, these authors reported no difference between any of the methods tested. All methods were reported to be highly correlated with PP on the acid soils.

Phosphorus Sorption Isotherms

The equilibrium in soils between sorbed and solution P also has been described through sorption isotherms. Such isotherms have been reported by Fox and Kamprath (1970) to include both the I and C values as defined by Williams (1967) and described in an earlier section. Employed in soil-P studies have been both the Freundlich and the Langmuir sorption isotherms.

The Freundlich equation is

$$x/m = kc^n \qquad [1]$$

where x is μg of P sorbed, m is adsorbent in g, c is the solution P concentration in μg/ml, and k and n are constants. Sorption of P by silt loams and silty clay loams from Illinois with pH range from 4.8 to 6.0 was shown by Kurtz, DeTurk, and Bray (1946) to follow a Freundlich-type isotherm. Russell and Low (1954) found that P sorption on kaolinite also obeyed the Freundlich equation. Olsen and Watanabe (1957) reported that the Freundlich equation generally applies to a wider range of equilibrium P concentrations and for larger amounts of sorbed P than does the Langmuir described below.

The primary advantage of the Langmuir equation over the Freundlich is that an adsorption maximum can be calculated from the Langmuir equation. The linear form of the Langmuir equation is

$$\frac{c}{x/m} = 1/kb + c/b \qquad [2]$$

where c, x, and m are as defined in equation [1], b is the sorption maximum, and k is a constant. However, Olsen and Watanabe (1957) reported that in a 24-hour equilibration period with various acid Ultisols, the P concentration could not exceed 9×10^{-4} M for the linear relationship to exist.

Compared with Freundlich and Langmuir equations, better estimations of P retention by 24 acid soils was found by use of a rearrangement of the least squares parabolic equation (Gunary, 1970). By inclusion of a square-root term, the equation is

$$\frac{c}{x/m} = A + D\sqrt{c} + Bc \qquad [3]$$

where c, x, and m are as described in equation [1] and A, D, and B are constants.

Recently, two, and possibly three, kinds of adsorption sites with differing affinities for P have been postulated by Syers et al. (1973). These workers used the Langmuir equation in studies of sorption of added P by Brazilian Oxisols and Ultisols of low, moderate, and high ability to sorb P. Plotting the data according to the conventional Langmuir equation, they found two linear relationships. These were interpreted as P sorption by sites differing widely in P affinities. By rearranging the Langmuir equation to the form

$$x/m = b - (x/m)/(kc) \qquad [4]$$

where the terms are as defined in equations [1] and [2], they found that the P-sorption curve could not be satisfactorily resolved into two straight-line components. From this result, they contended the existence of a third type of site for P sorption was possible. However, previous work by Kurtz and Quirk (1965) showed that small or no reductions in P-sorption maxima resulted after large P additions to acid Red-Brown Earths and Lateritic Podzols. They suggested that P did not permanently occupy the initial adsorption sites, but with time formed discrete P minerals.

In Typic and Rhodic Paleudults, Langmuir-defined P-sorption maxima and surface areas were closely related ($r = 0.96$) in studies by Olsen

and Watanable (1957). They suggested that surface adsorption of P is likely to occur in the initial adsorption stages. In acid Oxisols with various P fertilization histories, quantitative relationships between Al-P, Fe-P, or Ca-P and Langmuir adsorption isotherms were not found by Kurtz and Quirk (1965). They concluded from this that sorption maxima were not related to any particular P fraction in the soil.

In a study by Woodruff and Kamprath (1965), the P-sorption maximum of a Typic Paleudult had to be completely saturated to obtain maximum yields in comparison with P sorption of three Typic Hapludults which had more clay but did not require that their P-sorption maxima be completely saturated to obtain such yields. Olsen and Watanabe (1963), stated that diffusion possibly becomes a limiting process in P uptake more rapidly in sandy soils than in fine-textured soils. Therefore, Woodruff and Kamprath (1965) concluded that a sandy soil requires a much higher equilibrium solution P concentration to supply adequate amounts of P for plant growth than does a fine-textured soil.

Efficiency of Phosphate Fertilizers

Phosphate Fertilizers

Conventional P fertilizers such as OSP and CSP were reported by Hauck and Koshino (1971) to result in 5-25% recovery of applied P in the crop. This incomplete recovery of applied P fertilizers was attributed by the authors to rapid dissolution and consequent release of high concentrations of P primarily in unavailable forms.

To control the dissolution rates of P fertilizers, two primary approaches have been followed: 1) use of compounds with limited water solubility, such as rock phosphate (RP) (Ensminger, Pearson, and

Armiger, 1967), acidulated RP (McLean and Logan, 1970), or ammonium phosphate (AP) (Webb and Pesek, 1958), and 2) modifying soluble materials, primarily by various coatings to slow their nutrient release to the soil solution (Army, 1963). Nearly 40 such coatings have been patented in the United States by O'Conner (1965), Formaini (1967), Bidlack and Bidlack (1967), Blouin and Rindt (1967), and Goodale and Frump (1968).

One of the coatings developed by Blouin and Rindt (1967) at the Tennessee Valley Authority is an essentially impervious coat of elemental S with a microcrystalline soft wax sealant, and microbicide, usually coal tar. They reported that the sealant slowed water-vapor transfer through the S coating, while the coal tar retarded microbial decomposition of that sealant and possibly affected transformation of the S coating. When used with CSP, this product is termed SCSP and has various release characteristics. The P release through this coating was stated by the developers to be dependent on coating thickness, intactness of sealant, microbicide effectiveness, soil incorporation, soil temperature, and soil water content. They found that dissolution rate of P from the coated pellet was substantially slower than that of an uncoated pellet, subsequently allowing a more even apportionment of P over the growing season of crops.

Secondary Forms of Phosphate Fertilizers in Soil

When fertilizer containing principally $Ca(H_2PO_4)_2 \cdot H_2O$ (MCP) was applied to acid soils, Lindsay, Lehr, and Stephenson (1959) reported that water vapor was adsorbed by the pellet establishing a wetting zone and allowing water movement from the pellet to the soil, and due to the low pH of 1.5 of the escaping solutions, appreciable quantities of Al,

Fe, Mn, K, and Ca were dissolved from the soil. After addition of MCP fertilizers to a wide variety of Florida soils, among them Typic and Rhodic Paleudults, Fiskell (1965) also reported dissolution of large quantities of Al, Fe, and Mn. In the ionic environment of the fertilizer pellet, a wide range of secondary P compounds were noted by Lindsay et al. (1962) to be precipitated from solution. Identification of these compounds and those in subsequent studies by other authors has employed the use of X-ray diffraction. Included among identified reaction products between water-soluble orthophosphate fertilizers and soils have been dicalcium phosphates (DCP), $CaHPO_4 \cdot 2H_2O$ and $CaHPO_4$ (Brown and Lehr, 1959; Lehr, Brown and Brown, 1959; Lindsay et al., 1962; Das and Datta, 1968; Bell and Black, 1970b), octocalcium phosphate (OCP), $Ca_8H_2(PO_4)_6 \cdot 5H_2O$ (Lehr and Brown, 1958; Lindsay and Taylor, 1960; Lindsay et al., 1962; Bell and Black, 1970a, 1970b), hydroxyapatite (HAp), $Ca_{10}(OH)_2(PO_4)_6$ (Lindsay and Taylor 1960; Murrmann and Peech, 1968), and fluoapatite (FAp), $Ca_{10}F_2(PO_4)_6$ (MacIntire and Hatcher, 1942; Lindsay and Taylor, 1960; Murrmann and Peech, 1968). These transformations are considered significant in that the solubility and availability of these phosphates have been reported by Lindsay and Taylor (1960) to decrease in the same order as their appearance in the soil, i. e.,

$$DCP > OCP > HAp > Fap.$$

In addition to crystalline secondary P fertilizer compounds, amorphous Al-P and Fe-P compounds were always present as reaction products of P fertilizer and soil (Lindsay and Taylor, 1960; Lindsay et al., 1962; Taylor, Gurney, and Moreno, 1964; Das and Datta, 1968). As discussed earlier, Juo and Ellis (1968) have found these amorphous Al-P and Fe-P compounds to be relatively plant available.

The presence or addition of other soil compounds or fertilizers such as KCl, NH_4NO_3, or K_2SO_4 near $Ca(H_2PO_4)_2 \cdot H_2O$ has been found to so complicate the dissolution process that reaction products cannot be described in a simple system (Taylor and Gurney, 1965b). Among the most common compounds known to form in such situations are calcium ferric phosphates, calcium aluminum phosphates (Lindsay and Taylor, 1960; Lindsay et al., 1962; Taylor et al., 1964; Das and Datta, 1968), and potassium and ammonium taranakites (Lindsay and Taylor, 1960; Lindsay et al., 1962; Taylor and Gurney, 1965a, 1965b). Also present have been found gypsum or related compounds (Bouldin, Lehr, and Sample, 1960; Taylor and Gurney, 1965b).

Solid phases remaining in the residue of 60 to 80 mesh MCP granules after 3 weeks of reaction time in a Typic Hapludult were identified by Bouldin et al. (1960) to be almost exclusively dicalcium phosphate dihydrate (DCPD) with traces of anhydrous dicalcium phosphate (DCPA). The fraction of added P remaining as DCPD was predicted by the authors to be 21.7%, while the observed fraction was found to be 20.7%. Allmaras and Black (1962) applied 32 to 60 mesh CSP in which P was present almost entirely as orthophosphate to 14 different soils, including two acid Paleudults. After a 2-week growth of sorghum in the greenhouse, the authors found only 14% of the applied CSP was recovered from the residual granules.

Plant Responses to Phosphate Fertilization

Field Response

Fertilizer placement

Corn yields increased with change from low to high water solubility

of banded P fertilizers applied to acid soils low in available P (Webb and Pesek, 1958). On twenty field sites in Iowa from 1951 to 1956, these workers used CSP, among other fertilizers, with the fraction of available P in water-soluble form ranging from 10-100%. With increasing water solubility of phosphates applied at 13.4 kg P/ha on a Floyd silt loam in 1955, corn yields were reported by the authors to increase from 3519 to 4416 kg/ha. They concluded that for satisfactory yield responses on the Iowa soils used, banded fertilizers should not contain less than 60% of their P in water-soluble form. Similar evaluation of corn yields as related to increasing water solubility was made using broadcast P fertilizers, applied at 9-36 kg of available P/ha to 16 of the soils used in the previous study (Webb and Pesek, 1959). The percentage of water-soluble P was found by the authors to be of no importance in determining the effectiveness of fertilizers broadcast and plowed under for corn. The differing responses of these two studies were attributed by the authors to the fact that a minimum of soil-fertilizer reaction occured when a fertilizer was banded in comparison to the mixing from incorporation of broadcast fertilizers. Therefore, they stated that the effectiveness of the banded fertilizer was probably determined to a large extent by the fertilizer characteristics rather than by the nature of the soil-fertilizer reactions, while the opposite was true of broadcast fertilizer.

The relative effectiveness of banded and broadcast P fertilizers on three acid soils, among them a Typic Hapludult, and two alkaline soils was investigated in the greenhouse by Terman, Bouldin, and Lehr (1958). On the acid soils which were low in available P (< 1.5 ppm extractable by reagent 4), P fertilizer applied in bands produced higher

yields of ryegrass and sudangrass dry matter than did broadcast and incorporated fertilizer.

Residual effects

The effect on corn yields of large initial P applications followed by smaller annual applications to a Rhodic Paleudult was investigated by Robertson, Thompson, and Hutton (1966) for a 4-year period. Initial applications of CSP were 123, 246, 469, and 592 kg P/ha; annual amendments as OSP were 15 and 29 kg P/ha. Since the authors reported no significant differences in corn yields between rates over the time period, it was evident that the lowest P rate of 123 kg/ha was as efficient as the higher rates in satisfying the demands of the crop. Phosphate at 0, 336, 672, and 1,344 kg P/ha was applied by Younge and Plucknett (1966) to quench the P-fixation complex of a Hawaiian Typic Gibbsihumox. The field experiment indicated that only the highest P rate supplied sufficient P to produce adequate yields of pangolagrass-legume pasture over the 6-year test period.

To a Typic Hapludult with a high P-fixation capacity of 719 kg P/ha, Kamprath (1967) had added CSP in rates of 0, 177, 343 and 685 kg P/ha in 1956. The initial application of the highest P rate was reported by the author to supply adequate P for growth in 1964. When 25 kg P/ha were added to plots which had received the two intermediate rates, the total P supply was noted to produce high corn yields. The author concluded that the P added initially was not lost irreversibly, but was available for plant growth in subsequent years. A similar such result was reported by Fox, Plucknett and Whitney (1968). These workers measured the efficiency of P applications made 9 years earlier to a Gibbsihumox in Hawaii and concluded that 64 to 80% of the applied P could

be used by future crops grown on this soil. The residual effectiveness of 10-year-old P applications to a Typic Hapludult was judged by Fox and Kamprath (1970) to be 28-50%. They contended that this lower efficiency, as compared to that reported by Fox et al. (1968), was due to the fact that this Hapludult had been cropped annually with wheat or corn since it was last fertilized, while the Gibbsihumox, with its grass-legume mixture, had not been mixed since it was first fertilized. Fox and Kamprath (1970) also reported a residual P response in a Typic Paleudult fertilized 2 years previously with 0, 50, and 100 kg P/ha. To an acid Aguic Plinthic Dystropept in Sierra Leone, West Africa, Brams (1973) applied OSP at rates of 0, 30, 60, and 90 kg P/ha. After cropping with corn and rice, peanuts and rice, and peanuts for 3 years following P application, the author reported no differences in crop yields at any of the rates. Although the check P level initially contained 55 kg P/ha, the worker concluded that residual P could be utilized for extended periods without soil P becoming a limiting factor.

Foliar Composition

In a review of nutrient concentration in plant tissue, Bates (1971) stated that foliar composition was affected by soil properties, environmental conditions, cultivar tissue sampled, and physiological age of the plant. The relative water solubility of P fertilizers also has been reported to influence nutrient content in foliage. In a study previously discussed, Webb and Pesek (1958) reported that, as the fraction of available P in water-soluble form in fertilizer increased from 10 to 100%, the P content of corn ear leaves at early silking also increased from 0.217 to 0.228%. This same trend of increasing P content in corn tissue with change from low to high water solubility of P

fertilizers was observed by McLean and Logan (1970) on a low P-fixation capacity soil in the greenhouse trials. In a high P-retention capacity soil, these workers did not note this trend and stated that the higher water solubility of the P was a disadvantage to plant availability in this case, since this soil had the capacity to tie up most of the water-soluble P in forms initially unavailable to the corn seedlings.

Phosphorus concentrations in corn ear leaves, usually at silking, have been noted by a number of workers to be correlated curvilinearly with corn yields (Bates, 1971). Deficiencies of P were reported by Hanway (1962) to result in greater differences in percent total P in corn ear leaves and leaf sheaths than any other plant part. Although differences in P content of corn leaves and sheaths were noted to persist throughout the growing season, the author found they were maximum near silking time and, at that time, P content changes with leaf position on plant were small. In loamy soils, P concentrations in leaf tissue of corn ears at silking have been reported to range from 0.08-0.41% P (Table 2).

Table 2. Phosphorus content reported in corn ear-leaf tissue at early silking

P rates	P range in corn ear leaf tissue at 3 months of age	Reference
kg/ha	%	
various	0.08 - 0.33	Dumenil (1961)
0-134	0.15 - 0.37	Hanway (1962)
0-44	0.09 - 0.41	Peck, Walker, and Borne (1969)
0-68	0.17 - 0.34	Voss, Hanway, and Dumenil (1970)

MATERIALS AND METHODS

Site Selection

The site chosen for the field experimentation was at the Agricultural Research Center at Jay, Florida, and four years previously had been cleared of pine (Pinus elliotti). The soil was dominantly Red Bay fine sandy loam [Rhodic Paleudult], with the southern portion grading into Dothan fine sandy loam [Plinthic Paleudult][1]; both soils occur in the northwestern areas of Florida and southern Alabama. This soil was located nearly one mile from a previous long-term study reported by other workers (Robertson, Thompson, and Hutton, 1966). They demonstrated that corn grown on this soil responded to phosphatic fertilizer and to residual effects of this fertilizer several years after phosphorus fertilization was ceased.

Soil samples were taken at 0-36 cm and 36-56 cm depths on March 17, 1971. Thirty cores per depth sample were combined from the previously uncultivated site. Deep plowing to 36 cm and addition of 6.72 metric tons of dolomite/ha preceded by one month this soil sampling. Samples were stored in sealed plastic bags to maintain approximate field moisture prior to transport to the laboratory and subsequent analysis.

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[1] Soil Taxonomy of the National Cooperative Soil Survey, SCS, USDA, Washington, D.C., December, 1970.

Laboratory Experiments

Native Soil Phosphorus

Total phosphorus

Soil samples from the experimental site were analyzed for total soil P after Na_2CO_3 fusion according to the procedure of Jackson (1958). Interference of soluble silica with P determination was prevented by dehydration of soluble silica with 5N HCl and choice of the ascorbic acid-molybdate colorimetric procedure given by Watanabe and Olsen (1965). Details are given in a later section.

Inorganic phosphorus fractionation

The modification by Petersen and Corey (1966) of the sequential P-fractionation scheme previously proposed by Chang and Jackson (1957) was employed. The P fractions sequentially extracted by 0.5N NH_4F at pH 8.2, 0.1N NaOH, 0.3M $Na_3C_6H_5O_7 \cdot 2H_2O$ and $Na_2S_2O_4$, and 0.5N H_2SO_4 are termed aluminum phosphate, iron phosphate, reductant soluble phosphate, and calcium phosphate, respectively. The colorimetric determination of P in these solutions is described in a later section.

Plant-available phosphorus

As has been presented in the literature review, soil extraction with 0.03N NH_4F in 0.1N HCl (Bray and Kurtz, 1945) has been one of the methods best correlated with plant uptake of P and plant yields on Ultisols and Oxisols. For that reason, this extractant was chosen to determine plant-available P in the soil being studied.

A preliminary study was made with 0.03N NH_4F in 0.1N HCl to evaluate the effect of time of shaking on the amount of P extracted from the

soil using a 1:10 ratio of soil to solution. Shaking times used were 1, 5, 15, 20, 60, 120, 240, 360, 720, 1440, and 2880 minutes with two replications. Following a 20-minute period for filtration, solution P was analyzed.

A second preliminary study was made to determine the effect of sequential extractions on extractable P using a 1:10 ratio of soil to solution and shaking for 5 minutes. From these studies and the previous literature, it was decided to extract the soil from field plots with 0.03N NH_4F in 0.1N HCl at a 1:10 ratio of soil to solution with 5 minutes of shaking. Total time elapsed for shaking and filtration was 25 minutes.

A third preliminary study was performed to determine the influence of toluene on P retention by this Paleudult. Suspensions were prepared using 75 and 200 μg P/g soil employing 5 g of soil and 50 ml of solution with and without addition of two drops of toluene. These solutions were shaken twice per day for 30 minutes over a period of 6 days after which time solution P was measured.

Soil Retention of Applied Phosphorus

To determine which of the various methods for defining soil P retention gives the best description of P retention by this Paleudult, studies were initiated by equilibrating several levels of P with moist soil in the presence of 0.01M $CaCl_2$. On an oven-dry basis, 5 g of the moist, uncultivated Red Bay sample from 0-36 cm depth, screened to < 1 mm, were added to each of 72 polypropylene centrifuge tubes. As KH_2PO_4, 12 levels of P were applied: 0, 10, 50, 75, 100, 150, 200, 500, 1,000, 2,000, 3,500, and 5,000 μg P/g soil. Total solution volume in each sample was 50 ml. Equilibration times of 1, 72, and 144 hours on a

reciprocal shaker were used. Two replications of each level at each equilibration time were employed. To each of the samples that were to be equilibrated for 72 and 144 hours, were added 2 drops of toluene to deter microbial assimilation of added P. Upon completion of each equilibration, the suspensions were passed through a plastic assembly (Nalge) with a 0.2 μ-membrane filter to minimize the possibility of colloids and microbial presence in phosphorus analysis immediately following the filtration.

Phosphate potential

It has been suggested that the availability of soil P is determined primarily by the chemical potential of phosphate (Schofield, 1955). To test this hypothesis, phosphate potentials (PP) for each equilibrium solution of the preceding study were calculated by the following equation:

$$PP = \tfrac{1}{2}pCa + pH_2PO_4 = -\tfrac{1}{2}(\log C_{Ca} + \log\gamma_{Ca(H_2PO_4)_2}) - (\log C_{H_2PO_4} + \log\gamma_{Ca(H_2PO_4)_2}) \quad [5]$$

where $\log \gamma_i = (Az^+z^- \sqrt{\mu})/(1 + \alpha\beta \sqrt{\mu})$ [6]

in which constant A is 0.509, constant product αβ is 1.5, z^+ and z^- are the respective valences of the cation and anion species in solution and

$$\mu_i = \tfrac{1}{2} \Sigma_i C_i Z_i^2 \quad [7]$$

where C is concentration and Z is the valence of each ion in solution. For each addition of P, ΔP was calculated by the equation

$$\Delta P = (C_{Pi} - C_{Pf})/100 \quad [8]$$

where C_{Pi} and C_{Pf} are the initial and final P solution concentrations, expressed in μg/ml. Customarily, after determining PP and ΔP values, these points have been plotted as a Q/I, or Quantity/Intensity, curve

(White and Beckett, 1964) which was then extrapolated to obtain both PP at $\Delta P = 0$ and replaceable P. The slope of the curve was referred to by these authors as potential buffering capacity (PBC) and is herein referred to as P-sorption maximum (Psm). In the present studies, values obtained by graphical extrapolation of the Q/I curves were compared with those given by linear regression equations, and it was found that the equations presented a more accurate description of PP at $\Delta P = 0$ and replaceable P. For these equations, with PP employed as the Y variable and ΔP as X, PP at $\Delta P = 0$ was termed b in the equation $Y = mX + b$. Where ΔP was Y and PP was X, Psm and replaceable P were noted to be the respective m and b values in the linear equation.

Phosphate sorption isotherms

The amount of P held by the soil and the equilibrium concentration of P in solution were used in several equations to assess which most accurately described P retention in this soil. Though previously presented in the literature review, the employed equations are again defined in a manner consistent with the materials and methods section.

Freundlich equation.--This equation has been found to define soil P retention over a wide range of equilibrium P concentrations (Olsen and Watanabe, 1957). This equation is

$$x/m = kc^n \qquad [1]$$

where x is μg of P held, m is grams of soil, c is equilibrium concentration of P in μg/ml in solution, and k and n are constants.

Langmuir equation.--As has been pointed out in the literature review, this equation has been found to more closely define P retention in some soils than does the Freundlich (Olsen and Watanabe, 1957). Also,

it is possible to calculate the P-sorption maximum with Langmuir, while this is not possible with Freundlich. The Langmuir equation is

$$\frac{c}{x/m} = 1/kb + c/b \qquad [2]$$

where c, x, and m are as described in equation [1], b is the phosphate-sorption maximum, and k is a constant.

Square-root inclusion in parabolic equation.--Gunary (1970) found a better fit for P retention on a variety of soils by modifying the parabolic equation. His equation is

$$\frac{c}{x/m} = A + D\sqrt{c} + Bc \qquad [3]$$

where c, x, and m are as described in equation [1] and B, A, and D are constants.

Components Contributing to Soil Phosphorus Retention

As discussed in the literature review, soil Al, Fe, and organic matter have been found to be active in P retention by Ultisols and Oxisols. Accordingly, the approach taken in this study was to successively remove each of these components from the Rhodic Paleudult under consideration and then to determine P retention after various additions of P. The relative contributions of these factors to P retention should then be separated. In this study, moist uncultivated Red Bay fsl, taken at 0-36 cm and screened to < 2 mm, was used.

Organic matter removal

Organic matter removal by two reagents, hydrogen peroxide and sodium hypochlorite, was compared.

Hydrogen peroxide treatment.--To each of a set of nine 90-ml polypropylene centrifuge tubes were added 10 g of soil on an oven-dry basis,

10 ml of distilled water, and two 5-ml increments of 30% H_2O_2. The mixtures were stirred, left overnight, and placed in a water-bath at 65-70C for 30 minutes with an additional 5 ml of H_2O_2 added to each sample after the initial reaction ceased. To maintain a 10% solution, 10 ml of distilled water were added to each sample upon cooling. In succession, 50-ml washings of the soil were made with 1N $Ca(OAc)_2$, 1N $CaCl_2$, and distilled water. After a second wash with distilled water, the suspensions were shaken for 6 days and decanted. The stoppered samples were stored for 2 months. Determinations of suspension pH were made after storage. The washing were combined and analyzed for P, Al and Fe.

Sodium hypochlorite treatment.--Another set of samples with sodium hypochlorite was also used to remove organic matter. To a set of nine 90-ml polypropylene centrifuge tubes with 10 g of soil on an oven-dry basis were added 20 ml of 5.25% NaOCl adjusted to pH 9.5 immediately prior to use (Lavkulich and Wiens, 1970). These samples were placed for 15 minutes in a boiling water bath. To maintain a Na-saturated system, washings with 50 ml of 0.5N NaCl and 50 ml of 0.5N NaCl followed. A second 0.05N NaCl wash was shaken for 6 days and decanted. The stoppered samples were stored for 2 months after which time suspension pH determinations were made. The washings were combined and analyzed for P, Al, and Fe.

Citrate-dithionite-bicarbonate treatment

Six samples previously treated with H_2O_2 and six others with NaOCl were twice-treated with citrate-dithionite-bicarbonate (CDB) according to the method of Kunze (1965). To each of the above samples were added

40 ml of 0.3M $Na_3C_6H_5O_7 \cdot 2H_2O$ and 5 ml of 1M $NaHCO_3$. These suspensions were heated in a water bath to 75C with 2 g of solid $Na_2S_2O_4$ being added to each and then occasionally stirred over a 15-minute period. Ten ml of saturated NaCl were added to cause colloids to flocculate. Supernatants from both CDB treatments were combined and analyzed for P, Al, and Fe. The pH of the suspensions was determined.

Dissolution with hot sodium hydroxide

After 3 weeks of storage, three samples after the H_2O_2 and CDB treatments and three with NaOCl and CDB treatments were subjected to 50 ml of 0.5N NaOH at 100C for 2 minutes to permit dissolution of free alumina and amorphous aluminosilicates (Jackson, 1965). The samples were cooled rapidly by an ice-water bath to stop the reaction and then centrifuged at 2,100 rpm for 15 minutes. The solutions were decanted and analyzed for P, Al and Fe. The soils were washed twice with 50 ml of 1N $Ca(OAc)_2$ at pH 5, once with 50 ml of 1N $CaCl_2$, and four times with 50 ml of distilled water until a negative AgCl test in the washing indicated completion of salt removal. Measurements of electrical conductivity also showed no salts to be present after the washings and these washes were discarded.

Check treatments

The check treatments were thrice-replicated treatments of (1) soil and distilled water, (2) soil Ca saturated with 1N $Ca(OAc)_2$ at pH 5, (3) soil Ca saturated with 1N $CaCl_2$, and (4) soil Na saturated by 0.5N NaCl. Samples subjected to check treatment (1) were treated exactly as were the hydrogen peroxide-treated samples with the exception that whenever H_2O_2 was added to the peroxide-treated samples, distilled water

was added to check treatment (1) samples. For example, in check (1), 10 g of soil, 10 ml of distilled water and two 5-ml increments of distilled water were stirred, left overnight, and placed in a water-bath at 65-70C for 30 minutes with an additional 5 ml of distilled water added to each sample after the initial reaction of the peroxide-treated samples ceased. As in check (1) samples, check (2) samples were treated exactly as were the peroxide-treated samples with the exception that whenever H_2O_2 was added to peroxide-treated soils, 1N $Ca(OAc)_2$ at pH 5 was added to check (2) soils.

To the samples of check (3) were added the same quantities of 1N $CaCl_2$ as were added H_2O_2, CDB, and NaOH to the H_2O_2-CDB-NaOH-treated samples. All other conditions were similar. In other words, 1N $CaCl_2$ was substituted for H_2O_2, while the samples were subjected to exactly the same heating rates and times and washes as the peroxide-treated samples. These samples of check (3) then received 47 ml of 1N $CaCl_2$, instead of 40 ml of 0.3M $Na_2C_6H_5O_7 \cdot 2H_2O_2$, 5 ml of 1M $NaHCO_3$, and 2 g solid $Na_2S_2O_4$, and were heated to 75C. Instead of dissolution with hot 0.5N NaOH, check (3) samples were then subjected to dissolution with hot 1N $CaCl_2$. As check (3) substituted 1N $CaCl_2$ for H_2O_2, CDB, and NaOH, check (4) substituted 0.5N NaCl for NaOCl, CDB, and NaOH under similar conditions.

Phosphorus additions

After a month, each sample from the above treatments received two washes with 0.01M $CaCl_2$. This was followed by sequential additions of 0.31, 0.62, 1.24, 3.10, 6.20, and 31 μg P/g soil. Phosphorus was applied as $Ca(H_2PO_4)_2$ H_2O in 50 ml of 0.01M $CaCl_2$. Each level of P added was shaken for 30 minutes. The pH was determined and the suspensions

were then centrifuged for 15 minutes at 2,000 rpm. Supernatants were analyzed for P. At all levels of applied P, except 31.0 μg/g, undetectable amounts of P in solution required that the three replicates be combined for each of the ten treatments. These solutions were evaporated to dryness and taken up in 10 ml of 0.1N HCl containing 0.05 μg P prior to P analysis. All samples between sequential P additions and all supernatants prior to analysis were kept refrigerated. Total time elapsed in this study was 4 months.

Studies using ^{32}P

In a subsequent study of 2-weeks' duration, each of the above 30 samples received 50 ml of 0.01M $CaCl_2$ and 2 ml of a solution containing 42.0 μg P as $Ca(H_2PO_4)_2 \cdot H_2O$/g soil with ^{32}P present in the same chemical form. These soil solutions were shaken for 30 minutes once a day over a 3-day period. Following centrifugation at 2,000 rpm for 15 minutes and decantation, the amount of ^{32}P not sorbed by the soil was determined. The procedures for this and subsequent ^{32}P determinations are presented in the section on analytical procedures. Duncan's new multiple range test (Steel and Torrie, 1960) was used to determine which treatment differences were significant in this study and in all subsequent studies with ^{32}P.

In a concomitant study also of 2 weeks' duration, 10 g of the untreated soil were added to each of 15 centrifuge tubes. Treatments were 0, 1.55, 6.20, 15.5, and 31.0 μg ^{31}P as $Ca(H_2PO_4)_2 \cdot H_2O$/g soil added in 50 ml of 0.01M $CaCl_2$ per sample. The samples were shaken and allowed to stand overnight. Each sample then received 2 ml of solution containing 21.0 μg P/ml labeled with ^{32}P and supplied as $Ca(H_2PO_4)_2 \cdot H_2O$. These suspensions were shaken daily for 30 minutes over a 3-day period, then

centrifuged at 2,000 rpm for 15 minutes and subsequently analyzed for ^{32}P not sorbed by the soil.

After both ^{32}P studies, each soil sample was mixed with 50 ml of 1N NH_4OAc at pH 4.8, since this reagent had been found to remove dicalcium phosphate from soils (Fiskell and Spencer, 1964). These samples were shaken for 15 minutes, centrifuged at 2,000 rpm for 10 minutes, and decanted. The solutions were analyzed for ^{32}P. Determinations of pH and ^{31}P were also made.

Following the above extraction, 50 ml of 1N NH_4F at pH 8.2 (Fife, 1962) were added to extract the soils used in both ^{32}P studies. Samples were shaken for 15 minutes, centrifuged for 10 minutes at 2,000 rpm. The supernatants were analyzed for ^{32}P and Al. Since the pH values of the soil suspension treated with 1N NH_4F at pH 8.2 dropped to 6.0, supernatants were also analyzed for Fe. Analysis for ^{31}P in the supernatants was also made.

Fertilizer Phosphorus Dissolution

Dissolution of soluble salts from fertilizers has been reported by Blouin and Rindt (1967) to be retarded by coating the pellet with a combination of sulfur and wax. In a laboratory study, information was sought on the dissolution rates of conventional non-coated P fertilizers, such as ordinary superphosphate (OSP), concentrated superphosphate (CSP), and acidulated rock phosphate (ARP), compared to sulfur-coated CSP (SCSP).

Fertilizer dissolution without soil

In separate, covered 0.2 μ-membrane filters, were placed 5 g each of fertilizer granules of OSP (8.7% P), CSP (20.1% P), ARP (14.5% P, 5.8% water soluble), and $SCSP_a$ (15.5% P), and $SCSP_b$ (14.8% P). Every

week for 26 weeks each fertilizer was leached with 50 ml of distilled water. Determinations of pH and P were made on each leachate. Since the filter assemblies were covered to retard contamination and evaporation, fertilizer pellets remained moist between leachings. Following termination of the leachings, residual fertilizer pellets were analyzed for P and subjected to X-ray diffraction.

Fertilizer dissolution and retention in soil

This study was identical to the above one except that each of these P sources was mixed with 10 g, on an oven-dry basis, of the moist uncultivated Red Bay soil (0-36 cm depth, < 2 mm diameter). As in the concomitant study, weekly leachings with 50 ml of distilled water were added to each soil-fertilizer mixture for a 26-week period. Phosphorus and pH determinations were made on each leachate. Soil-fertilizer mixtures remained moist between leachings. After the experiment, the fertilizer pellets were removed manually from the soil, analyzed for P, and subjected to X-ray diffraction.

Field Experiments

To allow for adequate comparison of SCSP and CSP used under field conditions, six field studies were performed over a 3-year period on the site previously discussed. Corn (*Zea mays* L.) was chosen as the indicator crop. Wheat (*Triticum sativa*) was used as a cover crop in the fall and was plowed under a month prior to planting the second and third years.

Phosphorus Sources, Rates, and Placements, 1971

Phosphorus sources, rates and placements

In the main experiment, the P sources were granular CSP (20.1% P) and two SCSP fertilizers which were supplied by the Tennessee Valley

Authority. The SCSP fertilizers consisted of CSP coated with sulfur, 3% wax, 0.25% coal tar microbicide, and 2% diatomaceous earth conditioner. These sulfur-coated fertilizers differed only in percent P and amount of S-coating present. Source 1 of SCSP pellets contained 15.5% P, coated with 16.6% S based on total weight. Source 2 of SCSP contained 14.8% P and 19.3% S as coating based on total weight of the pellets.

Rates of CSP used were 28, 56, 84, 112, 140, 168, and 196 kg P/ha. Both SCSP fertilizers were used at the first five of the above rates. For these sources, the two higher rates were excluded since space was not available for the extra plots within the site. Check plots received no phosphate fertilizer. Each rate of each fertilizer was incorporated as broadcast and as row placement. Both placements are described in a later section.

Experimental design

Phosphorus sources, rates, and placement were compared in a split-plot arrangement. Main plots contained the various combinations of the P sources and rates, while the split-plot treatment was fertilizer placement. Main plots were arranged in a randomized complete block design with each treatment combination replicated four times. This study consisted of 144 plots, each 4.38 x 9.11 m. Each plot contained four rows of corn with the two outside ones serving as border rows between treatments and the inner two being those from which soil, plant, and yield data were collected.

Fertilization

The soil was prepared for planting and stakes were placed along the perimeter of the plot boundaries. On March 17, 1971, the area was to

receive a uniform broadcast application of 149 kg/ha of N as NH_4NO_3, 112 kg/ha of K as KCl, and 37 kg/ha of gypsum as a source of S. However, the first replication received four times the above rate of fertilization due to an equipment error. At each rate, one-half of each plot received P fertilizer broadcast uniformly by hand; the other half-plot received P fertilizer in two bands, each 5-6 cm wide and 7-8 cm from each of the four planting rows in the plot. The fertilizer was incorporated carefully with a rotary hoe to minimize horizontal displacement of the P fertilizer. On May 14, all plots received 75 kg/ha of N as NH_4NO_3 as a sidedressing.

Planting and cultural practices

The field was planted with 'Pioneer' 3009B corn two days after fertilization. The four rows per plot were 91 cm apart, with seed spacing at 15-cm intervals. Where necessary, a uniform stand was obtained by replanting two weeks later at the above spacing. When the corn was 30-cm high, the stand was thinned to 30-cm spacing to give approximately 25,860 plants/ha. Later in the season, the field was sprayed for control of corn earworm. Irrigation was not used in this study. Throughout most of the season, rainfall distribution (Appendix Table 28) was sufficient to prevent evidence of wilting due to drought injury.

Plant sampling

Entire corn plant tops, excised at soil level, were sampled from the border rows of each plot on May 17, 1971. Samples consisted of 8 plants per plot where plants were small, and 4 plants per plot where plants were large. These plants were desiccated in a drying room and

ground by a Wiley mill through a stainless steel sieve. One g of each ground sample was ashed for 2 hours at 350C and for 4 hours at 600C. Details of plant analyses are given in a subsequent section.

At silking stage on June 12 and 13, 1971, corn ear-leaf samples from eight plants from the two inner rows of each plot were taken. For those plants not silking, the fifth leaf below the whorl was taken, since the nutrient composition of these leaves has been found to resemble most closely that of the corn ear leaves at silking (Hanway, 1962). These samples were dried and ground as described above.

Soil sampling

Soils were sampled from each plot on June 23, 1971, at which time the corn growing on these plots was at the late-silking stage. Six cores, 0-15 cm, were taken between plants within the two inner rows of each plot. Samples were air-dried on greenhouse benches to cease dissolution from P fertilizer pellets and to facilitate removal of any of these pellets or their fragments prior to analysis. After having passed the soil through a 2-mm sieve carefully to avoid crushing fertilizer pellets, these pellets were removed manually before analysis. All soils were extracted with 0.03N NH_4F in 0.1N HCl as described in an earlier section. The subsequent P analysis is described in a later section.

Soils were sampled at harvest on September 16, 1971, in the same manner as at the earlier date. All plots were sampled, except those with band placement at rates of 56, 112, 168, and 196 kg P/ha. Soils were air-dried, sieved, extracted, and analyzed for P as described above. Fertilizer pellets manually removed from samples before extraction were subjected to X-ray diffraction to identify compounds present in the pellet residue.

Harvesting

Corn was hand-harvested from the two inner rows of each plot on September 14 and 15, 1971. Ears from each plot were shucked and weighed. Moisture percentage of the ears was determined and yield weights were adjusted to 14% moisture since yields are reported at this commonly accepted moisture level. Numbers of stalks and ears in these two inner rows were recorded for each plot. Six ears from each plot were dried, shelled, weighed, and kernel weight was determined as a percentage of total ear weight.

Since the corn had remained on the stalks for approximately a month after reaching maturity, some ears in several plots suffered racoon damage. In such cases, the average ear weight for undamaged ears on that plot was substituted for that of each damaged ear.

Statistical analysis of data

This split-plot field study was in actuality a 5 x 3 factorial in rates and sources plus the three additional treatments of check, CSP at 164 and 196 kg P/ha. Therefore it was decided to place the emphasis of the analysis of variance on the factorial set of treatments. The sum of squares associated with rate in each analysis was partitioned into regression components by means of orthogonal polynomials. Responses analyzed were P content of corn plant tissue at pre-silking stage, P content of corn ear-leaf tissue at late silking stage, P content of soil when plants were at late-silking stage, corn yield, average ear weight, kernel weight as percentage of ear weight, number of ears, and ears/stalk. Linear and curvilinear correlation coefficients were obtained from corn yields against soil P levels at silking and at harvest, corn yields against P, Al, Fe, Ca, K, Mg, Mn, Zn, and Cu content of corn plants prior

to silking, corn yields against P, Al, Fe, Ca, K, Mg, Mn, and Si content of corn ear leaves at silking, P levels in corn plants prior to silking against the other nutrient levels in corn plants prior to silking, and P levels in corn ear-leaf tissue at silking against each of the other nutrient levels in corn ear leaves at silking.

Fertilization with Mixtures of Coated and Non-coated Phosphorus Fertilizers, 1971

Design and cultural practices

The purpose of this study was to investigate the effect on corn yield of various combinations of SCSP and either pelletized ordinary superphosphate (OSP) containing 8.7% P, or the pelletized CSP used in the main experiment. Six different combinations of each uncoated source with SCSP (15.5% P) were used, varying amounts of each from 0 to 100% by 20% increments with P rate held constant at 84 kg/ha. This fertilizer was applied broadcast. Each treatment combination was replicated four times using a randomized complete block design. This study consisted of 48 plots, each 4.38 m x 9.11 m. Each plot contained four rows of corn, with soil, plant, and yield data being collected from the two inner ones.

Due to this study being located adjacent to the one previously discussed, all fertilization other than P treatments, planting, and cultivations were identical to those of the first study and were performed on the same dates.

All plant and soil samplings and procedures and the corn harvest were identical to those of the first study, with the exception that soil samples were taken from this second study only at harvest time.

Statistical analysis of data

Analysis of variance was performed on the same responses analyzed in the previous study. In order to maximize amount of information recovered, the sum of squares associated with percentage SCSP in the fertilizer mixture was partitioned into regression components by means of orthogonal polynomials. Linear and curvilinear correlation coefficients were obtained for the same combination of factors as given in the previous study.

Phosphorus Sources, Rates, and Placements, 1972

Fertilization

This study was a continuation on the same plots of the P source, rate, and placement study previously discussed, with a major modification in P fertilization. In the previous experiment, two placements of P fertilizers were studied, whereas in the continuation, only plots where P was applied broadcast were refertilized in 1972. Thus this modification allowed for the study of the residual effect of coated and non-coated P sources. Used as P sources on the refertilized plots were CSP (20.1% P) and SCSP (15.5% P), with each being applied to the plots where this same P fertilizer, coated or non-coated, was used the previous year. Since the previous year the greatest response to P was obtained at the lowest rate, the amount of P applied on the refertilized plots was one-half that of the previous year, e. g., plots receiving 28 kg/ha in 1971 received 14 kg/ha in 1972. Thus the rates applied were 14, 28, 42, 56, and 70 kg P/ha. However, no further P fertilizer was applied on the plots with the two highest levels of CSP in 1971. Again, check plots received only the blanket N and K fertilization. Fertilization of the field with 150 kg N as NH_4NO_3, 112 kg K as KCl, and 37 kg

gypsum/ha was applied broadcast on March 20, 1972. All P fertilizer was manually broadcasted.

The field was planted at 30-cm intervals on rows 91 cm apart with 'Pioneer' 3369A corn on March 21, 1972. This spacing gave approximately 25,860 plants/ha. When the plants reached about 60 cm in height, 56 kg/ha of N as NH_4NO_3 were sidedressed. Cultural practices and pest control were uniform across all experimental treatments and were consistent with the practices of the Agricultural Research Center at Jay, Florida. Weed control was excellent from the use of 'Bladex' herbicide. Irrigation supplied 1.25 cm of water to the plants after any week when natural rainfall (Appendix Table 67) was insufficient to supply this amount.

Plant sampling

At late-silking stage on June 13, 1972, five corn ear-leaf samples were taken from the two inner rows of each of the 144 plots. For any plants not yet silking, the fifth leaf below the whorl was taken. Leaf samples were treated in the same manner as those of the previous year and analyzed for P, Al, Fe, Ca, K, Mg, and Mn.

Soil sampling

Prior to refertilization and planting, soils were sampled from all plots which were to remain as residual plots. This sampling of March 20, 1971, consisted of six core samples per plot, taken at 0-15 cm. Soils were dried, extracted, and analyzed employing the same procedures as previously outlined.

Soil samples were taken from all plots on June 14, 1972 when the corn was at the late-silking stage. Methods of sampling, drying, ashing,

and extraction for subsequent P analysis were the same as those used for previous soil samples.

Harvesting

The corn was harvested from this field study on August 23, 1972, using the same procedures as had been used the previous year with one exception. To determine kernel weight as a percentage of total ear weight, three ears, rather than six, were taken from each plot.

Statistical analysis of data

The statistical approach for this 5 x 3 factorial study plus the three additional treatments was alike that of the previous year. Again, emphasis was placed on the factorial set of treatments in the analysis. The sum of squares associated with each rate in each analysis was partitioned into regression components by means of orthogonal polynomials. Responses analyzed were P in corn ear-leaf tissue at late-silking stage, corn yield, average ear weight, and kernel weight as percentage of ear weight. Linear and curvilinear correlation coefficients were obtained from corn yields against soil-P levels at preplanting, corn yields against soil-P levels at corn silking, corn yields against soil-P levels at harvest, corn yields against P content of corn ear leaves at silking, and P levels in corn ear leaves at silking against each other nutrient concentration in corn ear leaves at silking.

Various Combinations of Coated and Non-coated Fertilizers with and without Strip Mulch, 1972

This study involved four factors each at two levels run in four replicates of a randomized complete block arrangement. Due to site size, only 12 of the 16 possible treatment combinations were used. The design

was essentially a 3/4-replicate of a 2^4 factorial with the 48 plots being the same size as those of previous studies.

Used as fertilizer sources in this study were SCSP and CSP, urea and S-coated urea (SCU), KCl and S-coated KCl (SKCl). The SCU supplied by TVA, contained 34.8% N, 19.5% S, 3.0% wax sealant, and 0.25% coal tar microbicide. The SKCl, also supplied by TVA, contained 22.9% K, 26.1% S, 3.0% wax sealant, and 0.25% microbicide. A black polyethylene strip mulch, 25 cm wide (Hayslip and Iley, 1966), was used with various combinations of the fertilizers. Treatments employed were CSP and SCSP each in combination with urea and KCl with and without plastic mulch, CSP and SCSP each in combination with SCU and SKCl with and without plastic mulch, CSP and SCSP each with SCU and KCl without mulch, and CSP and SCSP each with urea and SKCl also without mulch.

Fertilization, planting, and cultivation practices

From the various P, N, and K sources used, each plot received 42 kg P, 168 kg N, and 140 kg K/ha. All fertilizer was applied manually as a band between the corn rows on March 21, 1972. Plastic strip mulch was placed by machine to cover the fertilizer bands on either side and between the two inner rows of each plot. Approximately 7 cm of each edge was covered with soil by the strip mulch applicator. Planting, additional fertilization, and cultivation procedures were identical to those of the previous study and were performed on the same dates. All plant and soil samplings and the corn harvest were identical in all respects to those performed in the residual P study previously discussed.

Statistical analysis of data

Since the design of the experiment was related to the quarter replicates of the 2^4 factorial, the factorial effects were joined in

chains or sets of four. Treatment combination determined the four members of each chain. By assuming one of the four members in each chain to be negligble, it was possible to estimate the three remaining effects. The factor with the greatest number of interactions, usually three or greater, in each of the four chains was the one considered negligible to allow analysis of the other factors. Analyses of variance were carried out on corn yield, average ear weight, and kernel weight percentage of ear weight. Linear and curvilinear correlation coefficients were obtained from the same combinations performed in the residual P study.

Evaluation of Residual P from Previous Two Years, 1973

These two studies were continuations on the same plots of the two previous studies of 1972, except that no P was applied in 1973. Blanket fertilization of the field was alike with the previous year and applied in mid-March, 1973. Planting with the same variety and spacings as employed the previous year was one day after fertilization. All cultural practices were uniform across the treatments and followed those of the previous year. Irrigation was not employed. Rainfall was sufficient throughout the season (Appendix Table 98) to prevent any appearance of drought injury to the corn.

Plant sampling

At late-silking stage on June 17, 1973, five corn ear-leaf samples were taken from the two inner rows of each of the 192 plots. For any plant not silking, the fifth leaf below the whorl was taken. Leaf samples were treated in the same manner as those of the previous year and were analyzed for P, Al, and Fe.

Soil sampling

After the blanket fertilization, but prior to planting, soils were sampled from all 144 plots of the main experiment, i. e. that study which in 1972 evaluated residual P. This soil sampling in mid-March, 1973, consisted of six cores per plot taken at 0-15 cm. Soils were stored in sealed plastic bags prior to the sieving and analysis procedures as previously described for other soil samplings.

Harvesting

Corn was harvested on August 22, 1973, from all plots of both experiments using the same procedures as were used the previous year.

Statistical analysis of data

The statistical approaches for both experiments were alike those of the previous year. Responses analyzed were P in corn ear-leaf tissue at late silking and corn yield. Linear and curvilinear correlations were obtained from corn yields against soil-P levels at preplanting, corn yields against P content of corn ear leaves at silking, and P levels in corn ear leaves at silking against both Al and Fe concentrations in corn ear leaves at silking.

Analytical Procedures

Clay Mineralogy and Associated Properties

Pretreatments

Pretreatments are necessary before effective mineralogical analysis can be performed (Kunze, 1965). However, since any pretreatment will affect the clay somewhat, the mildest treatment which would accomplish the purpose was chosen. Removal of soluble salts, di- and tri-valent

cations, and residual lime carbonates from Red Bay fsl, 0-36 cm, < 1 mm, was accomplished with acid sodium acetate according to the procedure of Jackson (1956). Organic matter was removed from the sample by hydrogen peroxide oxidation as described by Douglas and Fiessinger (1971). Free-iron oxide removal from the sample was accomplished by two successive citrate-dithionite-bicarbonate (CDB) treatments (Mehra and Jackson, (1960). The CDB supernatants were analyzed for Al and Fe as described in a later section. To disperse this treated soil while removing little amorphous material, 1N Na_2CO_3 was used to bring the soil solution pH to 9.5 as recommended by Rich and Zelazny.*

Washings and triturations with water at pH 10 through a 4.4 μ sieve were used to separate sand from silt and clay in the sample (Day, 1965). Silt was separated from clay by centrifugation at 2,000 rpm for 5 minutes in a 200-ml glass centrifuge bottle filled to the 10-cm level with the above water. After decantation, water was again added to the 10-cm mark, the suspension was stirred with a rubber-tipped stirrer at high speed, centrifuged at 1,500 rpm for 10 minutes, and decanted. The above procedure with centrifugation at 1,000 rpm for 2 minutes was repeated until the supernatant was clear. The settled fraction was classed as silt, while the supernatant was labeled clay. Sand, silt, and clay in the sample were quantitatively determined by weight. Clay was not fractionated. The supernatant was adjusted to pH 4 with 6N HCl to induce flocculation and subsequent concentration of the clay fraction (Kunze, 1965).

*L. W. Zelazny, personal communication.

Clay mineralogical analyses

X-ray diffraction.--A 225-mg portion of the separated clay was mounted by suction onto each of four ceramic tiles (Rich, 1969). Subsequently, two tiles were saturated three times with 5 ml of 1N $MgCl_2$, washed twice with distilled water, and solvated with 5 ml of 20% glycerol solution. The remaining two tiles were saturated three times with 5 ml of 1N KCl and washed twice with distilled water. X-ray diffractograms were obtained of Mg-saturated, glycerol-solvated samples with and without 100C treatment. Also subjected to X-ray diffraction were K-saturated samples without heat treatment and then with heating in an oven at 110, 300, and 550C. Blank tiles were inverted over samples in the oven to inhibit peeling. The diffractograms were run from 3 to 30 degrees 2θ on a General Electric XRD-700 instrument with Ni-filtered CuK_α radiation. Radiation was detected with a proportional counter. Instrument settings were a potential of 25 KV and a 25-ma current. The respective goniometer scan and strip-chart drive speeds were 2θ and 1.27 cm per minute. Scale expansion and zero offset were 775 and 8, respectively, while range was 10K. Angles were converted to angstrom units (A) from a prepared chart.

Differential thermal analysis.--The clay fraction was saturated twice with 1N $MgCl_2$, washed six times with distilled water to a negative AgCl test, dried at 40C, ground to pass a 4.4 μ sieve, and desiccated over $Mg(NO_3)_2$ for 72 hours at 56% relative humidity (Barshad, 1965). A 100-mg portion of the sample was then sandwiched between previously fired (1000C) asbestos around the chromel-alumel thermocouple according to the procedure of Reneau and Carlisle (1971). The sample holder was then connected to a transistorized circuit and heated in an inconel

block in a Deltatherm D2000 DTA instrument. Settings were 25% sonsitivity using a heating rate of 10C per minute from room temperature (23C) to 1000C. A standard of Ward's Brazilian gibbsite, < 4.4 μ, was prepared, packed, and heated in the same manner as was the clay sample. Endothermic reaction areas were measured by tracing the endothermic peaks on tracing paper of uniform texture and weight, cutting out the peak area, and weighing these traces. Slope ratios of endothermic peak sides as an indication of kaolinite and halloysite were made as described by Bramao et al. (1952).

Infrared analysis.--One mg of the air-dried clay remaining from DTA preparation and 400 mg of spectroscopic-grade KBr were dried at 105C and ground for 30 seconds in a plastic "Wig-L-Bug" with a stainless steel ball. The mixture was then placed in a stainless steel die in a Carver Laboratory Press, Model M, with a vacuum of 8,000 psi applied for 5 minutes (Mortensen, Andersen, and White, 1965). Infrared patterns of the nearly transparent pellets were obtained from 4,000 to 650 cm^{-1} on a Model 700 Perkin-Elmer IR-Spectrophotometer at a scan speed of 8 minutes. Instrument calibration was made with standard polystyrene film. Ward's Brazilian gibbsite was used similarly for a reference pattern.

Selective dissolution with hot NaOH.--Dissolution of the clays by boiling 0.5N NaOH was performed (Hashimoto and Jackson, 1960). To a previously dried (105C) and weighed polypropylene centrifuge tube was added a previously dried (105C) 75-mg sample of the Red Bay clay and 80 ml of 0.5N NaOH. The mixture was boiled rapidly for 2.5 minutes, cooled, centrifuged at 2,000 rpm for 5 minutes and decanted. A second 8-ml aliquot of 0.5N NaOH was added, mixed, centrifuged, and decanted.

To the soil was added 80 ml of 1N HCl. The suspension was mixed, centrifuged, and supernatant was discarded. Successive 50-ml increments of water and acetone were added, mixed, centrifuged, and decanted. The centrifuge tube with the sample was dried overnight at 105C and weighed. Weight loss is normally attributed to non-crystalline material and organic matter dissolved by the treatment; however, Dixon (1966) showed that up to 98% of gibbsite can be dissolved by hot NaOH dissolution. Accordingly, a Ward's Brazilian gibbsite standard was treated in the same manner as the clay. Weight loss of clay after treatment was attributed to the non-crystalline material, organic matter, and gibbsite dissolved.

Selected clay properties

Specific surface area.--The ethylene glycol monomethyl ether (EGME) method of Carter, Heilman and Gonzalez (1965) was employed to determine surface area of the clay. A 1.2-mg sample of Red Bay clay was placed in a tared aluminum dish and dried to a constant weight over P_2O_5 in an evacuated dessicator. Three ml of EGME were added to the sample forming a mineral-adsorbate slurry which was subsequently equilibrated in a $CaCl_2$-monoglycolate dessicator until constant weight was obtained. Surface area was determined according to the relationship.

$$A = Wg/(Ws \times 2.86 \times 10^{-4}) \qquad [9]$$

where A is specific surface in m^2/g, Wg is weight of EGME retained in sample, Ws is weight of dried sample in g, and 2.86×10^{-4} is the amount of EGME required to form a monolayer on a 1-m^2 sample.

Clay-bound organic matter.--The Walkley-Black (1934) method for easily reduced organic matter was used to determine the amount of clay-

bound organic matter. To both a blank and 0.5 g of oven-dried (105C) clay were added 10 ml of 1N $K_2Cr_2O_7$, followed by gentle swirling and rapid addition of 20 ml of concentrated H_2SO_4. After standing for 30 minutes, 200 ml of H_2O and 5 drops of orthophenanthroline-ferrous complex indicator were added immediately prior to titration. Titration with 0.5N $FeSO_4$ to a red-brown end-point followed and organic matter content was calculated.

Clay chemical analyses

Cation exchange capacity.--To 50 mg of Mg-saturated, salt-free clay, dried at 105C, were added 200 ml of 1N NH_4NO_3. The mixture was shaken for 4 hours, centrifuged at 2,000 rpm for 5 minutes, and the supernatant was analyzed for Mg. From the Mg present in solution, CEC was determined.*

CDB-extractable cations.--Supernatants of CDB extraction were analyzed for Fe, Al, and Si. To prevent $Na_2S_2O_4$ interference with the Fe analysis, 5 ml of the CDB supernatant plus 30 ml of H_2O were heated at 75C for 15 minutes. Dropwise addition of 30% H_2O_2 was made until the full ferric yellow color persisted and 1 ml of excess H_2O was added. After continued heating for 15 minutes, the solution was cooled to 25C and 3 drops of 6N HCl were added. Iron in this modified CDB extract was determined on a Perkin-Elmer Model 303 DU Atomic Absorption Spectrophotometer with an acetylene-air oxidizing flame at a wavelength of 2,483A. Aluminum and silicon were determined directly from the CDB extracts on the same spectrophotometer with a nitrous oxide-acetylene flame at wavelengths of 3,093 and 2,516A, respectively. These elemental

*L. W. Zelazny, personal communication.

analyses were performed by the Soil Science Analytical Service Laboratory, University of Florida.

Soil Particle-Size Distribution

Particle-size distribution was measured by two separate methods. After dispersing 25 g of air-dried soil in 5% sodium hexametaphosphate (Calgon), particle-size distributions were determined using the Bouyoucous hydrometer method as described by Day (1965). Particle-size distribution was also quantitatively measured by weight after the pretreatments were performed in the above clay mineralogy study.

Soil Chemical Analyses

Phosphorus

All soil extractants were analyzed for P using the Murphy and Riley (1962) ascorbic acid reductant technique as modified by Watanabe and Olsen (1965). This technique has been found to be ideally suited for use in soil P determination (John, 1970, Alexander and Robertson, 1970). Eight ml of the ascorbic acid reductant reagent were used per 50 ml containing appropriate aliquots of either sample or standard solutions. Standards were prepared in the same reagents as the soil extracts, at 0, 0.04, 0.1, 0.2, 0.4, and 0.6 ppm P. The transmittance was measured at 882 mμ by a Beckman B Spectrophotometer. Phosphorus concentrations in the extracting solution were obtained from the standard curve, which obeyed Beer's law, and from the appropriate dilution factors.

Prior to analysis of all extracts containing NH_4F, it was necessary to add 15 ml of 0.8M H_3BO_3 per 50 ml of total volume to prevent F from interfering with the molybdenum blue color in the P determination (Jackson, 1958). Neither the boric acid nor the fluoroborate formed

interfered with P color development by the above procedure.

Soils sampled on June 14, 1972 from the main field experiment were extracted with 1N NH_4OAc at pH 4.8 by the University of Florida Extension Soil Testing Lab. Subsequent P analysis was by the chlorostannous-reduced molybdophosphoric blue color method as presented by Jackson (1958).

Radioactive ^{32}P.--Determination of ^{32}P was made by adding 1 ml the extract to 5 ml of PPO-POPOP (Bray, 1960) and recording counts by a Packard Tri-Carb Liquid Scintillation Counting System Model 314 EX with setting at 950 V and 10^4 count maximum or 100 minutes for accuracy. Internal quenching did not pose a problem in any of the samples. Radioactive decay of samples was corrected by use of ^{32}P standards in each group analyzed.

Other analyses

pH.--Soil pH determinations were made on 10-g samples of uncultivated Red Bay fsl and soils sampled on June 14, 1972, from the main field experiment. A 1:1 soil to distilled water ratio was used. After 1 hour of intermittent stirring, the pH was read potentiometrically by inserting the glass electrode in the soil sediment and the reference electrode in the suspension (Peech, 1965). The meter was standardized with buffer solutions at pH 4 and 7.

Determinations of pH were also made on soil samples after H_2O_2, NaOCl, and CDB treatments for various component removal in the above P retention study. These readings were made using an Orion single-cell electrode with the meter standarized as above.

Organic matter.--Soil organic matter in 0.5 g of soil dried at 105C was determined by the Walkley-Black (1934) method as previously described.

Aluminum.--Aluminum analysis of most soil extractants was by atomic absorption spectroscopy as described above. The exceptions were the two sets of ^{32}P samples extracted by 1N NH_4F which were analyzed for Al by the aluminon procedure by Yuan and Fiskell (1959).

Iron.--Iron determination in most soil extractants was by atomic absorption spectroscopy as described above. The exceptions were the two set of ^{32}P samples extracted with 1N NH_4F. These extractants were evaporated to dryness in 50-ml breakers. To each beaker 25 ml of distilled water were added and vigorously mixed. A 5-ml aliquot of each solution was mixed well with 1 ml of 0.02% orthophenanthroline reagent, 1 ml of 10% hydroxylamine solution, and 10 ml of 1N NH_4OAc at pH 4.8. Standards containing 0, 5, 10, 15, and 20 μg Fe and samples were read at 490 mμ on a Beckman B Spectrophotometer. Iron concentrations in the samples were obtained from the standard curve and appropriate dilution factors.

Calcium, magnesium, and potassium.--The June 17, 1972 samples which had been extracted by 1N NH_4OAc at pH 4.8 were analyzed for Ca and K using a Beckman B spectrophotometer and for Mg by a Beckman DU by the University of Florida Extension Soil Testing Laboratory.

Plant Chemical Analyses

Ashed samples were digested in 1N HCl and each was brought to 50 ml volume with 1N HCl before analysis for P, Al, Fe, Ca, K, Mg, Mn, Zn, Cu, and Si.

Phosphorus

Phosphorus in the digested plant tissues was determined by the same ascorbic acid reductant technique (Watanabe and Olsen, 1965) as previously described.

Other elements

Measurements of Al, Fe, Ca, Mg, Mn, Zn, Cu, and Si in the plant ash were by atomic absorption spectrophotometry. Determinations of K in these samples were by flame photometry. These analyses were performed by the Soil Science Analytical Service Laboratory, University of Florida.

Fertilizer Analysis

Phosphorus

Phosphorus concentrations in all samples of CSP, OSP, and SCSP pellets were determined by the ascorbic acid reductant technique (Watanabe and Olsen, 1965). Five mg of a composite sample of fertilizer pellets analyzed were dissolved in 50 ml of 1N HCl. Measurement of P concentrations, after suitable dilution, was made by the colorimetric procedure described above.

X-Ray diffraction

Fertilizer granules of CSP, OSP, and SCSP before and after laboratory tests and those recovered from field studies were subjected to X-ray diffraction in order to identify the fertilizer compounds present. Powder mounts of the ground and sieved, $< 4.4\ \mu$, fertilizer pellets were used to obtain the X-ray diffractograms which were run from 3 to 60 degrees 2θ on a General Electric XRD-700 instrument with Ni-filtered CuK_α radiation. A proportional counter was used to detect the radiation. Instrument settings were as previously presented, with the exception that the range, scale expansion, and zero offset varied with the sample. X-ray data of fertilizer compounds as presented by Lehr et al. (1967) were used to identify the fertilizer compounds present.

RESULTS AND DISCUSSION

The composite sample Red Bay fsl taken to 36-cm depth was found by both the Bouyoucos hydrometer and quantitative weight methods to be composed of 68.2% sand, 13.7% silt, and 14.2% clay. Soil organic matter was found to be 1.14%. Weight loss upon drying to 105C was 4.55% and was attributed to organic matter and "water of constitution" (Jackson, 1956) associated with the sesquioxides in the soil. Selected chemical properties of this soil (Table 3) are similar to those reported from other locations of this soil series. Although dolomite at 6.72 metric tons/ha had been applied to this soil, tho small reaction time of one month prior to sampling explains the high acidity and low Ca levels found.

Clay Mineralogical Analysis

Since clay colloids of soils have been shown in the literature to influence P retention, a detailed study of the mineralogy of the clay fraction in this soil was undertaken. Complementary techniques of X-ray diffraction, differential thermal analysis, and infrared analysis were used to define the clay minerals present.

X-Ray Diffraction

X-ray diffractograms of the clay fraction of the Red Bay Ap horizon confirmed the presence of a vermiculite-chlorite intergrade [a vermiculite with aluminum hydroxyl interlayers], a true vermiculite [one without interlayers], kaolinite, gibbsite, and quartz. Potassium saturation

Table 3. Selected chemical properties of Red Bay fsl

		N KCl	NH_4OAc*			N HCl		
pH	CEC	Al	Al	Fe	Ca	Al	Fe	Ca
H_2O	meq/100g	----------	----------	ppm	----------	----------		
4.90	6.58	406	665	6.75	110	3570	935	545

*At pH 4.8.

produced sharp peaks at 14.6, 7.19, 4.87, 3.57, and 3.35A. A sharp, but skewed to the higher 2θ side, peak was found at 4.37A. The skewedness was attributable to a quartz peak at 4.28A which became evident upon heat destruction of gibbsite peak at 4.37A. Upon heat treatment of the K-saturated clay to 550C, the sharp 14.6A peak was observed to shift to a broad peak with maxima at 10.4 and 11.7A. The 14.6A shift to a 10.4A d-spacing denoted a vermiculite without interlayers, while the shift to 11.7A signified that hydroxy-aluminum remained interlayered in the vermiculite (Whittig, 1965). The disappearance of the 7.19 and 3.57A peaks following heat treatment of the K-saturated clay was indicative of kaolinite (Jackson, 1964). Gibbsite presence was confirmed in the clay by heat destruction of the 4.87 and 4.37A peaks (Whittig, 1965). The d-spacings of quartz at 4.28 and 3.35A were not affected by heat treatment. The diffractogram of the magnesium-saturated, glycerol-solvated clay showed a small 19.2A peak which could indicate montmorillonite presence (Whittig, 1965).

Differential Thermal Analysis

Differential thermal analysis of the clay produced a broad endotherm at 120C, a sharp endotherm at 310C, a smaller, but well-defined symmetrical endotherm at 530C, one at 970C, and an 880C exotherm. The slope ratio of the endotherm at 530C was found to be 1.04, thereby indicating kaolinite rather than halloysite was present (Barshad, 1965). However, it should be mentioned that electron micrographs of this clay did show some tubular halloysite to be present. Comparing DTA endotherms of 10 and 30 mg of standard gibbsite with the soil clay endotherms, 50.0% of the clay was identified as gibbsite. In a similar comparison with 5 and 10 mg of kaolinite standards, it was found that 13.6% of the clay was

kaolinite.

Infrared Analysis

The presence of gibbsite in this clay also was confirmed by infrared analysis. In agreement with previous work with this mineral (Van Der Marel, 1966; White, 1971), adsorptions bands due to OH groups of gibbsite were found at 3580, 3490, 3420, and 3370 cm^{-1} in both the reference gibbsite and Red Bay clay samples. The observation that the peak at 3420 cm^{-1} of the clay is deeper than that of the reference gibbsite possibly is caused by kaolinite, which also contains a peak from 3420 to 3440 cm^{-1}. The Al-OH lattice vibration peaks at 1020, 800, 740, and 670 cm^{-1} were noted in both the reference gibbsite and the clay. It is possible that the gibbsite peak at 1020 cm^{-1} was masked by the lattice vibrations of kaolinite from 1034 to 1010 cm^{-1} (Van Der Marel, 1966). The Si-O lattice vibrations of quartz at 1080 and the "quartz doublet" at 800 and 780 cm^{-1} (Farmer, 1971) were observed in the IR pattern of this clay. Lattice vibrations of kaolinite possibly could have contributed to bands recorded at 910 and 700 cm^{-1}.

Non-crystalline Components

Sequential dissolution with hot 0.5N NaOH dissolved 12.0% of the clay; this included some dissolved gibbsite since 10.7% of the gibbsite reference was dissolved by the same treatment and up to 98% of gibbsite has been shown to be dissolved by this treatment (Dixon, 1966). The amount of amorphous material, after adjustment for dissolution of gibbsite and clay-bound organic matter, was determined to be 3.2%.

Selected Clay Properties

Clay-bound organic matter was 3.45% of the total clay weight. The

specific surface area (SA) of the clay was 76.3 m^2/g, while cation exchange capacity (CEC) was 6.58 meq/100g. The bulk of these two parameters was attributed to the vermiculites, amorphous material, and clay-bound organic matter, since kaolinite, gibbsite, and quartz have quite small surface areas and CEC values. Found to be extractable by CDB treatment of the clay were 2770, 4290, and 216 ppm of Fe, Al, and Si, respectively.

In this clay, percentages of gibbsite, kaolinite, and clay-bound organic matter were 50.0, 13.6, and 3.5% respectively. By use of the observed CEC and SA values and the relative contribution of each of the clay components to these values, the clay also contained 5.5% interlayered plus true vermiculite, 3% montmorillonite, 23.3% quartz, and 1.1% amorphous material. In previous mineralogical studies of this soil by Fiskell and McCaleb (1953), Yuan et al. (1960), and Ferraz, Robertson, and Hutton (1968), gibbsite also was reported to be the dominant clay mineral with lesser amounts of the other above minerals also mentioned.

Native Soil Phosphorus

Fractionation of the total native P (70.5 μg P/g soil) in this soil demonstrated that more than one-half of this P was held in the 0.1N NaOH extractable or Fe-P form (Table 4). The Al-P, Ca-P, and reductant soluble-P, as defined by Petersen and Corey (1966), accounted for lesser amounts of native P. Greater than 50% Fe-P of the native P in other Red Bay samples was reported by Yuan et al. (1960) and Robertson et al. (1966).

As an indication of available P, 0.03N NH_4F in 0.1N HCl was used to extract the uncultivated soil (Table 4). As defined by the extractant

Table 4. Native soil P in Red Bay fsl

Extractant	P removed	
	µg/g soil	% of total
Na_2CO_3 fusion	70.5	
1N NH_4Cl	0	0
0.5N NH_4F	12.1	17.2
0.1N NaOH	38.6	54.8
0.5N H_2SO_4	6.0	8.5
CDB	9.0	12.8
	65.7	93.3
0.03N NH_4F + 0.1N HCl	5.2	7.4

used, approximately 12 kg P/ha of the native P were available to crops.

Using this same extractant, preliminary studies determined the effect of various shaking times and sequential extractions on P extracted (Tables 5 and 6). Although there was variation between P extracted at the various shaking times, the greatest difference found was due to a marked readsorption of P released at the 48-hour extraction period. By sequentially extracting the uncultivated Red Bay sample with 0.03N NH_4F in 0.1N HCl, successively decreasing amounts of P were released from the soil. This sequence of extractable P demonstrated that "available P" as defined by this reagent indicates a continuing supply of P rather than only an initial amount. Total P extracted by the five sequential treatments was equivalent to 28 kg P/ha.

Soil Retention of Applied Phosphorus

A preliminary study revealed that the presence of commonly employed toluene had no effect on P retention in this soil (Table 7). However, for consistency with previous investigations of P retention, toluene was used in these studies.

Phosphate retention data for this soil conducted at various equilibration times were treated according to the P-sorption isotherms of the Freundlich and Langmuir equations (Olsen and Watanabe, 1957), the square-root inclusion method of Gunary (1970), and the phosphate potential (PP) method of Schofield (1955). Percentage of P sorbed by the soil decreased as P rates increased from 10 to 5,000 μg P/g soil and increased as equilibrium times increased from 1 to 144 hours (Table 8).

Phosphorus Adsorption Isotherms

When dealing with P sorption in relation to theoretical equations,

Table 5. Effect of various shaking times on P extracted by 0.03N NH_4F in 0.1N HCl from uncultivated Red Bay fsl

Shaking time minutes	P extracted* µg P/g soil
1	7.05a
5	3.05ab
15	6.90a
20	3.30ab
60	5.65ab
120	4.90ab
240	3.00ab
360	2.90ab
720	2.30ab
1440	4.05ab
2880	0.05b

*Values not followed by the same letter are significantly different.

Table 6. Effect of sequential extractions with 0.03N NH_4F in 0.1N HCl on extractable P from uncultivated Red Bay

Sequential extraction number	P extracted* μg/g soil
1	3.30
2	2.45
3	2.35
4	2.25
5	2.25
Total	12.60

*No significance among extractable P values was noted.

Table 7. Toluene influence on P retention by Red Bay

Toluene	P added	P remaining in solution after 6 days
2 drops/50 ml	µg/g soil	µg/ml
Absent	75	0.5
Present	75	0.6
Absent	200	9.4
Present	200	10.4

*At same P amendments no difference between solution P was found.

Table 8. Phosphorus retention by uncultivated Red Bay fsl as influenced by P rates and equilibration times

P applied	P sorbed after					
	1 hr	72 hr	144 hr	1 hr	72 hr	144 hr
	µg/g soil			%		
0	-0.03	-0.11	-0.01	-	-	-
10	9.84	9.88	9.97	98.4	99.8	99.7
50	49.1	49.4	49.8	98.1	98.7	99.6
75	73.0	73.3	74.5	97.3	97.7	99.3
100	95.2	96.4	98.9	95.2	96.5	98.9
150	133.0	138.0	146.0	88.6	92.1	97.3
200	166.0	181.0	191.0	83.1	90.4	95.3
500	287.0	367.0	400.0	57.3	73.4	80.0
1,000	358.0	563.0	600.0	35.8	56.3	60.0
2,000	455.0	810.0	840.0	22.7	40.5	42.0
3,500	570.0	1,045.0	1,040.0	16.3	29.9	29.7
5,000	535.0	1,150.0	1,250.0	10.7	23.0	25.0

it is well to keep in mind the work of Hsu and Rennie (1962) which showed that data obtained from P precipitation by exchangeable Al on resin conformed to both Langmuir and Freundlich adsorption isotherms. Close agreement between P-fixation data and these isotherms, they concluded, did not necessarily imply an occurrence of an adsorption reaction in soils. In principle, as Hsu (1965) stated, precipitation and adsorption result from the same chemical force.

The pertinent data obtained by the various isotherms defining P sorption in Red Bay are presented in Table 9. For purposes of brevity, the methods employed and previously defined are referred to as Freundlich, Langmuir, and Gunary. The P-sorption rate maximum (Psrm) in the present studies is the amount of P retained at the highest rate in each range of P applied to the soil. In Table 9, r is the correlation coefficient of observed and theoretical P sorption, and Psm is the P-sorption maximum estimated by the various methods.

Phosphate retention as defined by several theoretical approaches was highly correlated with P sorption in Red Bay soil (Table 9). However, the correlations of some approaches with P sorption were better under certain equilibrium times and concentrations. At the rates of applied P from 500-5000 μg P/g soil at equilibrium time of 144 hours, the Freundlich estimation ($r = 0.9989$) of sorbed P more accurately described P sorption than did the Langmuir equation ($r = 0.9893$). This finding is in agreement with the statement of Olsen and Watanabe (1957) that the Freundlich relationship generally applied for large amounts of sorbed P. Freundlich estimation of sorbed P was poorest at the lowest equilibrium times and concentrations. With increase in both equilibrium time and concentration, Freundlich description of P sorption usually improved and

Table 9. Phosphate sorption maxima, correlation coefficients, and other parameters as defined by various approaches used to evaluate P sorption in Red Bay fsl

Factor measured	Ranges of applied P			
	10-150	10-200	10-5,000	500-5,000
	µg/g soil			
1-hour equilibrium				
Solution P, µg/ml	0.16-17.0	0.16-34.0	0.16-4,465	213-4,465
Psrm*, µg/g soil	133	166	535	535
Psm†(Langmuir), µg/g soil	150	176	548	584
Psm (Gunary), µg/g soil	165	273	719	602
Psm (P potential), µg/g soil	392	433	2,448	5,023
Correlation coefficient, r				
Freundlich	0.9552	0.9529	0.9635	0.9786
Langmuir	0.9990	0.9954	0.9958	0.9959
Gunary	0.9993	0.9986	0.9958	0.9959
P potential	-0.9953	-0.9876	-0.8215	-0.9425
Phosphate potential				
At $\Delta P = 0$	6.02	5.91	4.42	2.80
Replaceable P, µg/g soil	65	73	502	1,740

Table 9. Continued

Factor measured	Ranges of applied P			
	10-150	10-200	10-5,000	500-5,000
	μg/g soil			
72-hour equilibrium				
Solution P, μg/ml	0.12-11.9	0.12-19.2	0.12-3,850	133-3,850
Psrm, μg/g soil	138	181	1,150	1,150
Psm (Langmuir), μg/g soil	158	194	1,141	1,280
Psm (Gunary), μg/g soil	191	461	2,381	2,326
Psm (P potential), μg/g soil	408	469	2,847	5,430
Correlation coefficient, r				
Freundlich	0.9600	0.9649	0.9814	0.9986
Langmuir	0.9980	0.9871	0.9902	0.9961
Gunary	0.9988	0.9947	0.9998	0.9997
P potential	-0.9922	-0.9748	-0.8399	-0.9488
Phosphate potential				
At $\Delta P = 0$	6.13	5.98	4.59	3.02
Replaceable P, μg/g soil	66	78	517	1,744

Table 9. Continued

Factor measured	Ranges of applied P			
	10-150	10-200	10-5,000	500-5,000
	μg/g soil			
144-hour equilibrium				
Solution P, μg/ml	0.03-4.0	0.03-9.4	0.03-3,750	100-3,750
Psrm, μg/g soil	146	191	1,250	1,250
Psm (Langmuir), μg/g soil	164	202	1,193	1,339
Psm (Gunary), μg/g soil	226	347	2,857	5,000
Psm (P potential), μg/g soil	430	483	2,723	5,212
Correlation coefficient, r				
Freundlich	0.9645	0.9626	0.9812	0.9989
Langmuir	0.9969	0.9941	0.9870	0.9893
Gunary	0.9991	0.9993	0.9993	0.9993
P potential	-0.9901	-0.9828	-0.8362	-0.9359
Phosphate potential				
At $\Delta P = 0$	6.72	6.60	5.03	3.11
Replaceable P, μg/g soil	64	73	495	1,610

*Psrm is amount of P retained at the highest rate in each range of P applied to the soil.

†Psm is P sorption maximum estimated by the various methods at the indicated ranges of applied P.

approached 'r' values found for the Langmuir equation.

Langmuir description of P sorption by this soil was at its best at equilibrium concentrations less than 20 μg P/ml. Previous workers (Olsen and Watanabe, 1957; Rennie and McKercher, 1959; Weir and Soper, 1962) also reported close agreement between P sorption and Langmuir description of this sorption when equilibrium solution concentration was less than 20 μg P/ml. These above workers used respective equilibration times of 24, 6, and 6 hours. In the present study, as equilibration time was increased from 1 to 44 to 172 hours, correlations between P sorption and Langmuir decreased. This occurrence was attributed to the fact that P sorption with time increased and that Langmuir, having been theoretically derived for monolayer gas adsorption, did not accurately define this increased sorption.

Only a linear Langmuir relationship was reported by Olsen and Watanabe (1957), Rennie and McKercher (1959), Hsu and Rennie (1962), and Gunary (1970) over equilibrium ranges up to 14 μg P/ml. At a similar low-P range, Syers et al. (1973) found P sorption in some Brazilian Ultisols to be defined by two slopes of linear Langmuir relationships. The difference between single and double Langmuir slopes, according to Syers et al. (1973), was that insufficient data points were collected by the previous workers in this low-P range. Syers et al. (1973) used eight measurements, while the maximum used by the former workers was four. The data of the present study, using from five to six points in this low-P range, also plotted a single linear Langmuir curve at each equilibration time of 1, 72, and 144 hours (Fig. 1). It is possible that the two Langmuir curves reported by Syers et al. (1973) were attributable to their longer equilibration time of 72 hours as compared with

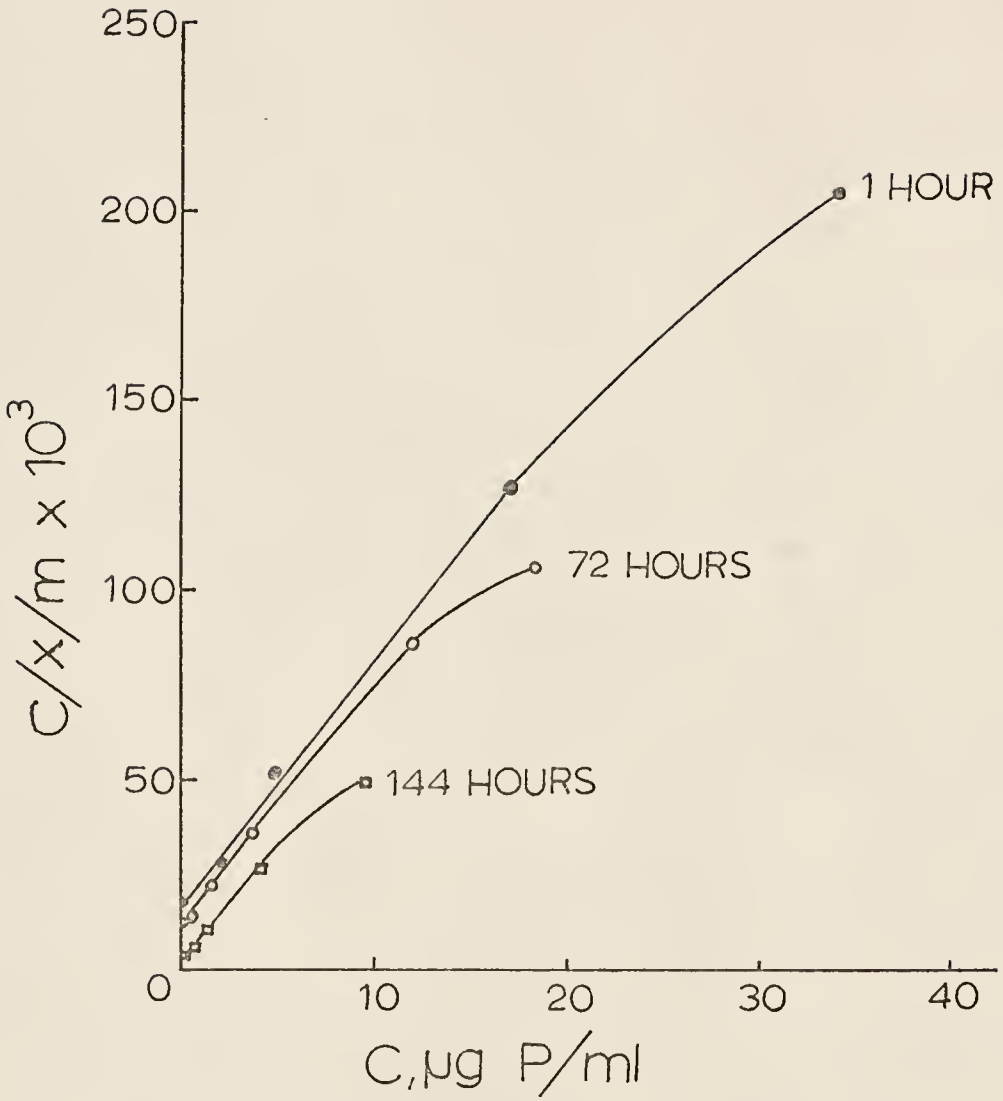

Fig. 1. Phosphorus sorption data for Red Bay fsl plotted according to Langmuir equation.

0.5 to 24 hours of the other studies. In the present study, as time of equilibration was increased, deviations from Langmuir linearity occurred at lower equilibrium concentrations (Fig. 1) and are reflected in the first two 'r' values at each equilibrium time (Table 9). After an hour of equilibration, linearity of the Langmuir sorption curve extended to applied P between 17 and 34 μg P/ml. After 72 hours, the deviation from linearity occurred between 11.9 and 19.2 μg P/ml. Following 144 hours of equilibration, the Langmuir curve became non-linear between 4.0 and 9.4 μg P/ml. Non-linearity of the Cambai soil of Syers et al. (1973) occurred at 2.0 μg P/ml. Phosphate-sorption maximum of the Cambai soil was 3.5 times that of Red Bay. It seems that two linear portions of the Langmuir curves of a soil can result at equilibrium concentrations less than 20 μg P/ml, if equilibrium time is at least for a period of 72 hours, or if the soil has a high P-retention capacity of at least 150 μg P/g soil, or a combination of both these factors.

Although the Langmuir equation more accurately described P sorption in Red Bay soil than did the Freundlich one at lower equilibrium concentrations and times, use of the parabolic equation by the method of Gunary (1970) gave the best estimation of sorbed P at all times and concentrations tested. Gunary (1970) also reported similar good fit on the 24 soils he investigated. Over all times and concentrations, his equation accounted for more than 99.5% of the variation in P sorption by Red Bay. Although no theoretical foundation for this equation exists, by defining a saturation maximum, the implication was that the soil will absorb only a given amount of P. At the various equilibrium times and concentrations, Psm values as defined by Gunary ranged from 1.1 to 3.7 times those

obtained by Langmuir maxima. Gunary (1970) also noted for his soils that Psm as defined by his equation was 1.4 to 2.4 times those defined by Langmuir equation. In the Red Bay soil, though P retention defined by the Langmuir equation increased with time, 96.0% of all P which was retained after 144 hours was already fixed by soil components after only 72 hours. Phosphorus retention as determined by Psrm was almost identical to Psm obtained from the Langmuir equation (Table 9). Over all ranges of equilibrium concentrations and all equilibrium times, Psrm was 93.8% of Psm by Langmuir. As compared with Psrm and Psm by Langmuir, Psm by Gunary appeared to overestimate P retention in this soil.

Phosphate Potential

The relevant variables obtained by treatment of the data according to phosphate potential (PP) technique of Schofield (1955) are presented in Table 9. As defined by Schofield (1955), PP is defined as 0.5pCa + pH_2PO_4. For these data, r values are correlation coefficients of observed and theoretical P sorption, and Psm is the sorption maximum estimated by this method at the indicated equilibrium conditions. Phosphate potential for $\Delta P = 0$ is located at the point where no P sorption or desorption occurs. The PP data presented in Table 9 are taken from linear regression equations employed as described in the materials and methods section.

Variation in P sorption by Red Bay soil was best estimated by PP values (R^2 = 99.1) when the lowest equilibrium time and concentration were used. Estimation of this variation by Langmuir was also observed to be best (R^2 = 99.8) at these lowest times and concentrations. As time and concentration were increased, correlations between PP and P

sorption in Red Bay soil decreased. The poorest correlations with P sorption obtained by any of the methods investigated were those of PP over the widest range tested. In these instances, PP only accounted for 71 to 76% of the variation in P sorption. Phosphorus sorption had been observed to be well correlated with PP at both ends of the entire concentration range; yet, over the entire range, these correlations decreased considerably. This occurrence was attributed to the exponential increase of ΔP which must be divided into several linear relationships to fit accurately linear regression equations (Fig. 2).

The Psm values as defined by PP, were noted to exceed those for Langmuir maxima by a factor of 2.4 to 8.6. At 1-hour equilibration, the ratio of Psm by PP to Psm by Langmuir at the lowest concentrations was found to be 2.6. With time increase to 72 or 144 hours, this ratio remained constant. This meant that neither P sorption as defined by PP nor that by Langmuir changed in relation to each other as time was increased. Over the wider concentration ranges, as defined by PP technique, 89.9% of all P retained after 144 hours was sorbed after only 1 hour. Similar values for Langmuir and Gunary were 45.9 and 25.2%, respectively. At the concentration range of 0.16-17 μg P/ml, Psm by Langmuir and PP at 1 hour were calculated to be 91.5 and 91.2%, respectively, of that sorbed after 144 hours. Therefore, when 150 μg P/g soil were applied to Red Bay under conditions of the present study, a rapid initial reaction and a slower subsequent reaction were noted to occur. As discussed in the literature review, two such reaction rates have been observed by numerous workers in various soils under similar laboratory conditons.

However, the low equilibrium concentration range at which Langmuir

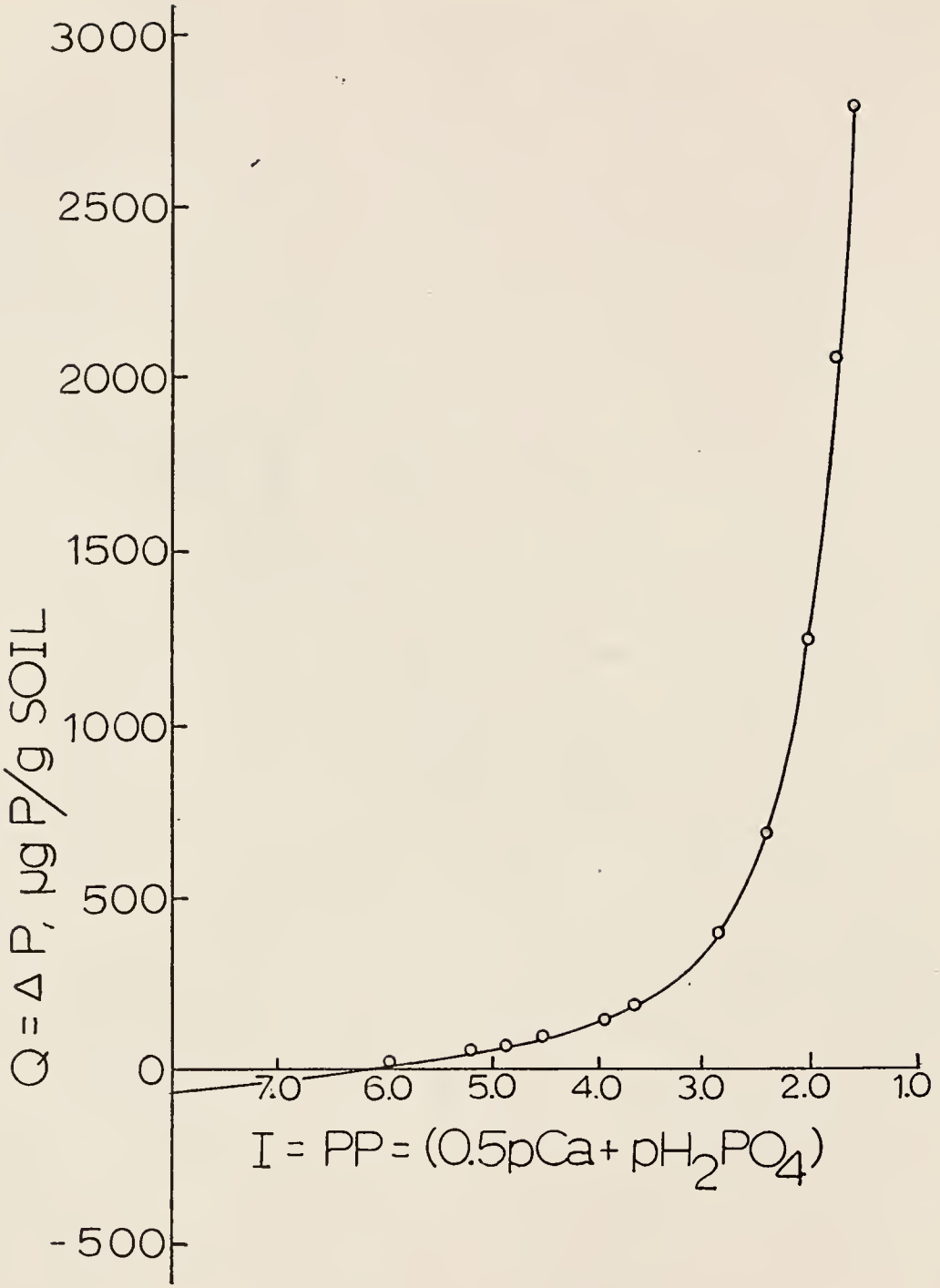

Fig. 2. Quantity/Intensity curve of P additions to Red Bay fsl after 1 hour equilibrium time.

was most definitive of P sorption in this and previous studies was unrealistic in that it did not approach the high P concentrations which are known to occur in the vicinity of a dissolving fertilizer pellet. Higher P rates, such as the 500-5,000 μg P/g soil rates, more closely simulated soil-P concentrations in the immediate vicinity of a fertilizer particle in the field. At these higher rates of P fertilization, the ratios of Psm at 1 hour were compared with Psm at 144 hours for the Psrm and Psm by Langmuir, Gunary, and PP methods; the values are 42.8, 43.6, 12.0, and 96.4% respectively. Using this ratio test, PP was clearly the best of the four methods and probably more closely approximated the zones of intercept of high-P reactions of fertilizer pellets and soil under field conditions.

Another advantage to PP description of P reactions in soils was that replaceable P could also be calculated. Replaceable P was defined earlier as that portion of sorbed P which can be replaced by ions other than phosphate; hence, this could be viewed as available P. At the lowest range of applied P after 1 hour equilibrium, 20.0% of the Psm by PP was found to be available, while at the highest range of applied P, which may be more indicative of field conditions, 34.6% of Psm was classed as available. After 144 hours, this replaceable P was found to be 30.9% of Psm values by the PP technique. Consequently, P sorbed by Red Bay soil was not entirely unavailable to plants and, as P rates increased, the replaceable P expressed as a percentage of Psm also increased.

However, use of PP as an indication of P retention and availability in soils did exhibit certain disadvantages. One was the fact that for all three equilibration times at a range of 500-5,000 μg P/g soil, values found by Gunary, Langmuir, and Freundlich equations more accurately

described P sorption in Red Bay soil than did the PP case. Also over the entire range of applied P, PP yielded lower correlations with Psm than did any of the sorption isotherms tested. The greatest drawback to use of PP in P-retention studies appeared to be the involved mathematical procedures which are required.

Although each examined approach exhibited certain advantages and disadvantages on Red Bay soil, certain generalizations could be drawn from the study. Over all equilibrium times tested and at equilibrium concentrations less than 20 μg P/ml, best correlations with Psm were provided by Gunary, Langmuir, and PP methods, in that order. As rate of applied P and time increased, Freundlich estimations of Psm surpassed those by Langmuir and PP. To provide an estimation of Psm, sorption tests on Red Bay soil by PP and Langmuir did not necessitate the usual 144 hours, but only 1 and 72 hours, respectively. Over the entire equilibrium concentration range, PP accounted for somewhat less variability in Psm values as compared with those of the other techniques. The Psm by the PP method overestimated Psm values found by the Langmuir method, but was approximately the same as that of Gunary at the highest P additions and time employed. Over the entire experimental range, the square-root inclusion into the parabolic equation by Gunary (1970) more accurately described P sorption in Red Bay soil than did treatment of the data by the other methods used.

Components Contributing to Soil Phosphorus Retention

Initial P retentions following the various pretreatments were less than definitive (Table 10), primarily due to the low level of applied P, which was 41.3 μg P/g soil. Treatment with NaOCl prior to P additions resulted in less P being retained by the soil than in any other pre-

Table 10. Phosphorus sorbed by uncultivated Red Bay fsl following various pretreatments for component removal

Pretreatment Reagent(s)	No.	P sorbed*
H_2O	1	98.3b
$Ca(OAc)_2$	2	98.1b
$CaCl_2$	3	98.9b
NaCl	4	99.4bc
H_2O_2	5	98.9b
NaOCl	6	90.5a
5 + CDB	7	96.6b
6 + CDB	8	95.6b
7 + NaOH	9	93.4ab
8 + NaOH	10	96.3b

*Differences defined by Duncan's new multiple range test (0.05) are significant for means not followed by the same letter.

treatment. Pretreatments 6, 8, and 10 using NaOCl also resulted in more Al and Fe being extracted than treatments 5, 7, and 10 with H_2O_2 (Table 11). Dissolution of amorphous material by NaOCl has been suggested by Zelazny and Qureshi (1973). The possibility that NaOCl dissolved some amorphous material from Red Bay soil is discussed in subsequent paragraphs.

Studies using ^{32}P

A continuation of the above study provided more conclusive results when ^{32}P was employed. The percentages of ^{32}P recovered from the pretreated soils by H_2O, 1N NH_4OAc (pH 4.8), and 1N NH_4F (pH 8.2) are given in Table 12 along with the percentage of P sorbed after each pretreatment. Final P-retention values by Red Bay soil after pretreatments 7-10 were significantly reduced compared to those after pretreatments 1-6. Treatments 7-10 included use of CDB extraction and, as shown in Table 11, substantial amounts of Fe and Al were removed by this extraction. The CDB-extracted Fe and Al were considered to be crystalline and have been shown in Florida Ultisols (Yuan and Breland, 1969), specifically in Red Bay series (Velez and Blue, 1971), to be more closely correlated with P retention than Al and Fe extracted by various other methods. Pretreatments 5 and 6 used for organic matter removal had no effect on final P sorbed by this soil.

Although the decreases in soil-P retention following pretreatments 9 and 10 were not found to be different from those of pretreatments 7 and 8, the hot 0.5N NaOH pretreatment showed that, to a limited extent, amorphorus aluminosilicates entered into some P retention by Red Bay soil. However, as was shown earlier in the clay mineralogical analysis of this soil, 10.7% of a crystalline gibbsite standard was dissolved by hot 0.5N NaOH dissolution. Since the clay of Red Bay was found to be

Table 11. Aluminum and iron removed from Red Bay fsl by various pretreatments prior to P addition

Pretreatment Reagent(s)	No.	Extracted by sequential pretreatment Al	Fe
		μg/ml	
H_2O_2	5	0	0
5 + CDB	7	2,070	10,500
7 + NaOH	9	1,290	1
NaOCl	6	5	1
6 + CDB	8	2,600	10,800
8 + NaOH	10	1,750	1

Table 12. Phosphorus recovered from and sorbed by pretreated soils following extraction with various solutions

Pretreatment Reagent(s)	No.	^{32}P recovery by* H_2O	1N NH_4OAc (pH 4.8)	1N NH_4F (pH 8.2)	^{32}P sorbed by soil
		%			
H_2O	1	2.9bc	4.8b	32.9e	59.4a
$Ca(OAc)_2$	2	5.9abc	5.6b	29.1e	59.5a
$CaCl_2$	3	1.8c	7.7ab	44.4cd	46.2a
NaCl	4	2.2c	7.0ab	47.6c	42.5a
H_2O_2	5	0.9c	7.3ab	44.5cd	47.3a
NaOCl	6	4.9abc	9.5ab	37.1de	48.5a
5 + CDB	7	2.5c	19.5ab	71.1ab	6.9b
6 + CDB	8	8.5a	21.0ab	63.8b	6.7b
7 + NaOH	9	1.9c	17.6ab	80.0a	1.7b
8 + NaOH	10	7.3a	22.3a	69.4b	1.1b

*Differences defined by Duncan's new multiple range test (0.05) are significant for means in columns not followed by the same letter.

50% gibbsite, apparent removal of amorphous aluminosilicates by 0.5N NaOH might actually be destruction of gibbsite sites for P retention. Although there is no definitive line which exists between crystallinity and non-crystallinity of soil clay minerals, it appears that the reduction in P retention upon treatment with 0.5N NaOH could be due to removal of some amorphous material and some less-crystalline gibbsite, both formerly active in P retention.

Following the various pretreatments and extraction with water, more P was recovered in solution from the NaOCl pretreatments, 6, 8, and 10, than from the others. As shown in the initial P-retention results (Table 10), NaOCl reacted with some soil component, possibly amorphous material, which was active in P retention, thereby reducing soil-P retention. As evidenced by Tables 10 and 12, this component was not affected by H_2O_2 treatment. Since there was no difference between P sorbed by soil between pretreatments 5 and 6, pretreatments 7 and 8, and pretreatments 9 and 10, it was apparent that the NaOCl-soluble component was removed by either 1N NH_4OAc (pH 4.8) or 1N NH_4F (pH 8.2). As shown by the P recovery by these reagents from soil with pretreatments 5-10, the NaOCl-extractable component was removed by 1N NH_4F (pH 8.2) from pretreatments 5, 7 and 9 containing H_2O_2 (Table 12). Analyses of these extracts showed that Al exceeded Fe up to 1000-fold. The NaOCl-soluble component was postulated to be an amorphous aluminosilicate which was active in P retention.

The 1N NH_4OAc (pH 4.8) extraction revealed that more P was removed with increasing treatment intensity from 1-10, but few differences were noted. This reagent, listed as reagent 10 in the literature review, had been chosen as an indicator of "available P" and to remove any DCP and

TCP (Fiskell and Spencer, 1964) present in the soil. Since the only value revealed to be significantly different from any others was that of pretreatment 10 from those of checks 1 and 2, it was concluded that neither the Ca-P forms nor available P was affected greatly by the pretreatments, with the exception of pretreatment 10.

Phosphorus recovery after extraction with 1N NH_4F (pH 8.2) generally increased as treatment intensity increased. These extractable P values from soil with the H_2O_2 pretreatments were found to be greater than those with the NaOCl pretreatments. As discussed previously, this was attributed to NaOCl having removed amorphous aluminosilicates active in P retention, while this fraction was not removed from the H_2O_2 samples until the NH_4F extraction. The observation that more P was recovered from checks 3 and 4 than that from 1 and 2 possibly was due to the fact that checks 3 and 4 were heated as were the CDB and NaOH pretreatments, while checks 1 and 2 were heated less harshly and were comparative with the H_2O_2 pretreatment.

Analysis of the NH_4F extracts revealed that amounts of extracted Al exceeded those of Fe by 100- to 1000-fold, even though pH of the NH_4F solution was noted to decrease from the initial 8.2 to an average of 6.0 after reaction with the pretreated soils. Quantities of Al and P recovered from NH_4F extracts and their ratios are presented in Table 13. The observation of greater Al removal by NH_4F from pretreatment 9 than from pretreatment 10 was attributed to apparent removal of this Al by NaOCl in pretreatment 10. A consistent trend could not be described with the Al to P ratios, although pretreatment or check 2 was recorded to have the greatest ratio of Al to P. Aluminum and P extracted by $Ca(OAc)_2$ pretreatment were not judged different from those for water

Table 13. Aluminum and phosphorus extracted by 1N NH_4F (pH 8.2) from various pretreated subsamples of Red Bay fsl

Pretreatment Reagent(s)	No.	NH_4F extractable* Al	P	Al/P
		---- µg/ml ----		
H_2O	1	35.5b	13.8e	2.57b
$Ca(OAc)_2$	2	51.0b	12.2e	4.17a
$CaCl_2$	3	37.5b	18.6cd	2.01b
NaCl	4	38.5b	20.0c	1.94b
H_2O_2	5	38.3b	18.7cd	2.05b
NaOCl	6	56.0b	15.6de	2.14b
5 + CDB	7	41.7b	29.8ab	1.40b
6 + CDB	8	56.0b	26.8b	2.06b
7 + NaOH	9	98.8a	33.6a	2.97ab
8 + NaOH	10	48.5b	29.1b	1.66b

*Differences defined by Duncan's new multiple range test (0.05) are significant for means in columns not followed by the same letter.

only. Aluminum extracted from pretreatments by the NH_4F reagent was not considered to be necessarily that associated with sites for P sorption, since Al to P ratios were found to be erratic and since basic NH_4F has been shown to remove elements other than Al which are active in P retention, namely Ca (Pratt and Garber, 1964; Bromfield, 1967; Blue, 1970). Excessive storage time, 2 months, possibly caused active Al to replace Al previously removed by pretreatments.

After H_2O_2 pretreatment, 47.3% of the applied P was held by the soil following the sequence of H_2O, NH_4OAc, and NH_4F extractions (Table 12). However, once these soils were CDB treated, P sorption decreased 7-fold, with P extracted by H_2O, NH_4OAc, and NH_4F treatments increasing several fold, correspondingly. After NaOCl pretreatment, the sorption trend also was noted following CDB treatment; P sorption decreased 7-fold from 48.5 to 6.7%, while P extracted by H_2O, NH_4OAc, and NH_4F treatments approximately doubled. Since crystalline Fe and Al have been described as being removed by CDB treatment (Yuan and Breland, 1969) and since following CDB treatment of this soil from 64 to 71% of applied P were found to be NH_4F extractable, it was postulated that, upon removal of crystalline Fe and Al, P initially held in Red Bay by these elements was retained on sites possibly associated with amorphous aluminum hydroxides. In summary, it was concluded that removal of organic matter and amorphous aluminosilicates had little effect on P retention, while CDB removal of crystalline Fe and Al greatly affected P retention in Red Bay fsl.

In a concomitant study, as ^{31}P additions to untreated Red Bay increased and the ^{32}P level was held constant, sequential use of H_2O, 1N NH_4OAc (pH 4.8), and 1N NH_4F (pH 8.2) extractions successively removed

Table 14. Phosphorus recovery from and sorption by Red Bay with several P amendments as extracted with various solutions

Treatment		^{32}P recovery by*			^{32}P sorbed by soil
^{31}P only	^{32}P tracer	H_2O	1N NH_4OAc (pH 4.8)	1N NH_4F (pH 8.2)	
- µg P/g soil -		---------- % ----------			
0	42	1.4b	5.8b	42.8b	50.0b
1.6	42	1.6b	6.5b	46.4b	45.5b
6.2	42	1.9b	7.4b	52.1b	38.6b
15.5	42	3.3ab	9.8ab	61.9ab	25.0ab
31.0	42	6.3a	13.3a	78.0a	2.4a

* Differences defined by Duncan's new multiple range test (0.05) are significant for means in columns not followed by the same letter.

Table 15. Aluminum and phosphorus extracted by 1N NH_4F (pH 8.2) from various subsamples of Red Bay fsl

Treatment		NH_4F extractable*		
^{31}P only	^{32}P tracer	Al	P	Al/P
- µg P/g soil -		----- µg/ml -----		
0	42	44.3a	21.0b	2.11a
1.6	42	53.5a	23.8b	2.25a
6.2	42	50.2a	29.6b	1.69ab
15.5	42	40.8a	43.1ab	0.94ab
31.0	42	34.2a	71.2a	0.38b

* Differences defined by Duncan's new multiple range test (0.05) are significant for means in columns not followed by the same letter.

large amounts of P (Table 14). However, by considering as unity the percentage of H_2O-extractable P, the NH_4OAc- and NH_4F-extractable P expressed as a percentage of total P removed were found to decrease 2- and 3-fold, respectively, as P rates increased. Evidently, P extracted by H_2O and 1N NH_4OAc (pH 4.8) increased more rapidly with increasing level of applied P than did values by 1N NH_4F extraction. Since Al recovered from NH_4F extracts did not increase with increasing levels of P recovered (Table 15), inference was given that only a portion of this Al was involved in P retention. Extractable Fe ranged from 0.12 to 0.26 µg/ml in these solutions. Calcium phosphates such as DCP and TCP have been shown by Bromfield (1967) and Blue (1970) to be removed by 0.5N NH_4F (pH 8.2). These phosphates were assumed to have been removed by 1N NH_4OAc (pH 4.8) (Fiskell and Spencer, 1964). However, the decreasing Al/P ratio with increasing P removal suggested that some element other than Al was holding the P. The element involved in this P retention was more than likely Fe since, once extracted by the NH_4F reagent, it would immediately precipitate at the prevailing pH of 6.0 and not be recovered in the extractants.

Fertilizer Phosphorus Dissolution

Fertilizer dissolution without soil

Phosphorus was observed to dissolve from SCSP fertilizers at a markedly slower rate than that coming from OSP, CSP, or ARP (Fig. 3). Of the total P released from the fertilizers during the 26 leachings, the first leaching of OSP, CSP, and ARP removed 90.5, 73.1, and 64.0% P, respectively. From the SCSP fertilizers employed (a, 15.5, and b, 14.8% P), only 0.4 and 1.2% of total P removed were contained in the initial leachate. In fact, nearly 20 leachings were required to remove

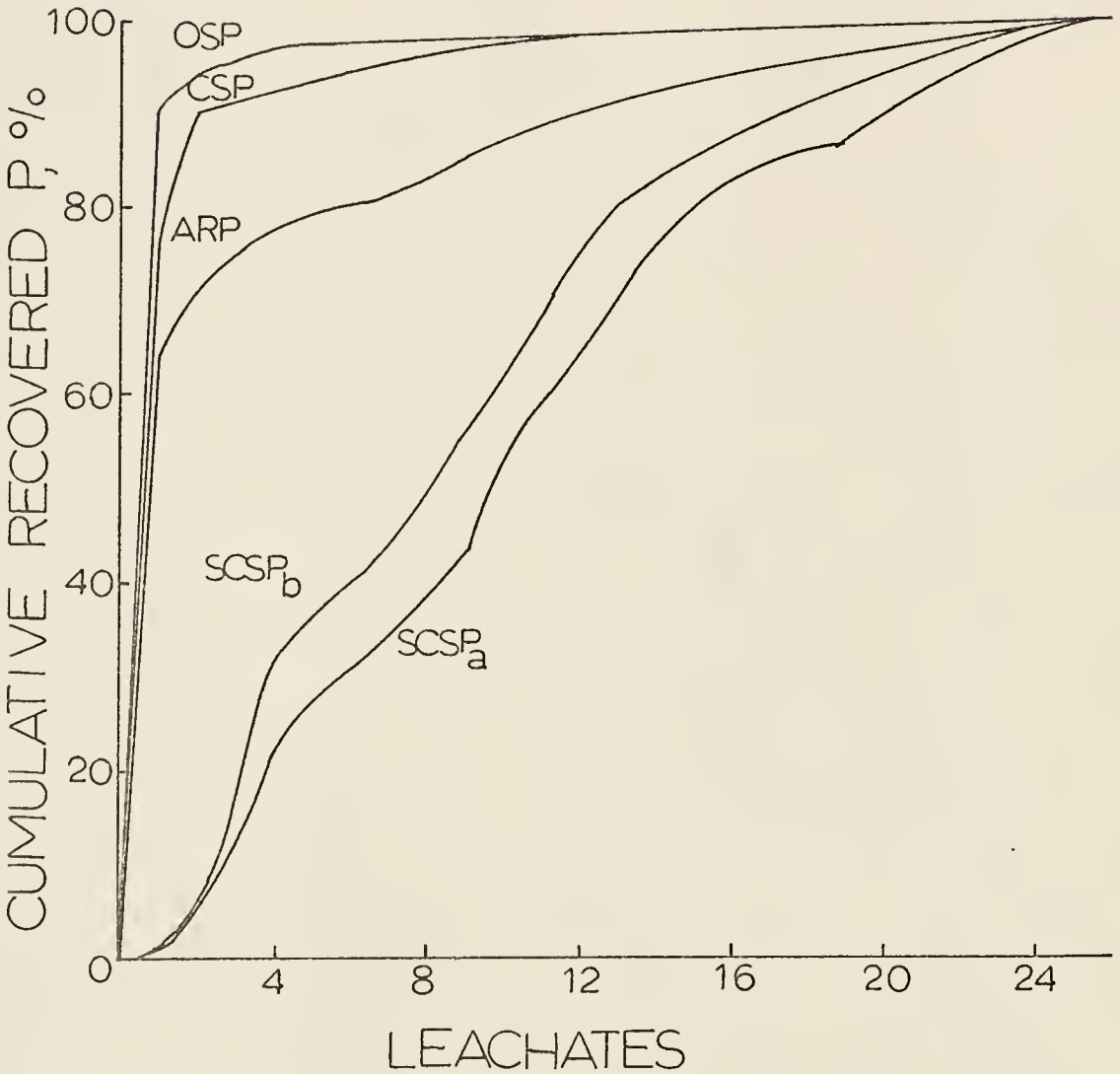

Fig. 3. Phosphorus cumulatively recovered in 26 leachings from various P fertilizers.

90% of the recovered P from SCSP sources, while these amounts were recovered in the first and second leachings of OSP and CSP. Phosphorus recovered from the P sources, given as percentages of the applied P, was noted to be 21.9, 46.0, 51.4, 59.5, and 71.8% for ARP, $SCSP_b$, $SCSP_a$, OSP, and CSP, respectively. However, similar leaching of other SCSP sources revealed that from 39.7 to 90.2% of the applied P could be recovered in the leachates. The variance in P release from SCSP pellets was attributed to non-uniform coating and to breaks in the sealant used. As was stated by Blouin and Rindt (1967), developers of the coating employed, P release through this coating was dependent upon uniform coating thickness and sealant intactness, among other factors. Pellets of SCSP which exhibited the aforementioned extreme P release variation were observed to follow a similar type of release curve to those of SCSP presented in Fig. 3.

Acidity released from the P sources was varied, although all sources but OSP manifested the same pattern of an initially low pH increasing with time (Table 16). Over the period of 26 weekly leachings, pH of leachates from CSP was observed to increase from 2.8 to 5.4. The pH from SCSP sources from second leachate to termination of study increased from 2.9 to an average of 3.7. Lower continual and terminal acidity of SCSP leachates as compared with those of CSP was attributed to oxidation of the S-coating with consequent H_2SO_4 formation and H_3PO_4 release.

Results of X-ray diffraction analysis of these residual pellets from laboratory studies are presented with those of residual pellets from field studies in a later section.

Fertilizer dissolution and retention in soil

Small soil to fertilizer ratios were used to present a more realistic

Table 16. Acidity in leachates from various P sources

Leachate no.	P sources				
	OSP	CSP	ARP	$SCSP_a$	$SCSP_b$
	pH				
1	3.07	2.78	3.30	3.80	4.44
2	4.31	3.57	4.15	2.85	2.86
3	4.88	4.27	4.50	2.79	2.74
4	4.94	4.46	4.80	2.77	2.75
5	5.12	4.37	4.90	2.94	2.99
6	5.01	4.08	5.10	3.08	3.09
7	4.92	4.08	5.25	3.04	3.05
8	4.81	4.08	4.80	3.00	2.87
9	5.13	4.18	4.90	3.01	2.84
10	5.23	4.33	5.10	2.85	2.85
11	5.18	4.46	5.20	2.96	2.97
12	5.09	4.64	5.10	2.99	3.07
13	4.81	4.41	5.10	2.97	3.04
14	4.78	4.47	5.30	3.08	3.10
15	4.80	4.55	5.10	3.08	3.40
16	4.77	4.44	4.90	3.11	3.11
17	4.74	4.62	5.00	3.41	3.23
18	4.72	4.89	5.10	3.54	3.34
19	4.87	4.83	4.90	3.48	3.37
20	5.00	5.00	5.10	3.40	3.60
21	4.80	4.90	4.85	3.40	3.80
22	5.10	5.10	5.10	3.50	3.80
23	3.10	5.10	5.00	3.40	3.80
24	3.00	5.20	4.90	3.50	3.80
25	3.10	5.30	4.70	3.70	3.90
26	3.16	5.42	4.90	3.61	3.88

Table 17. Phosphorus recovered and acidity in each 50 ml leachate of a 1:5 soil to fertilizer mixture

Leachate no.	P source			
	CSP		$SCSP_b$	
	P	pH	P	pH
	ppm		ppm	
1	500	3.4	78	4.5
2	390	4.0	100	3.2
3	130	5.0	210	3.3
4	62	4.8	260	3.2
5	42	5.0	315	3.1
6	38	5.2	220	3.2
7	30	5.3	98	3.5
8	27	5.3	68	3.8
9	22	5.2	50	4.0
10	19	5.0	40	3.4

Table 18. Phosphorus recovered in each leachate after P addition to Red Bay soil

Leachate no.*	P recovered†	
	CSP	SCSP
	------ P, ppm -----	
1	152.0	0.1
2	9.5	1.8
3	3.6	4.0
4	2.8	4.0
5	1.7	2.7
6	1.2	1.2
7	1.1	1.6
8	0.8	2.5
9	0.7	3.2
10	1.2	2.1

* Each is 50 ml water added per week to 150 g soil.

† Phosphorus applied from each source was 200 µg P/g soil.

approach of P dissolution and retention in the immediate vicinity of fertilizer pellets than is afforded by conventional P-retention studies using large soil to solution ratios. Since CSP and SCSP pelletized sources were those employed in field studies with Red Bay soil, emphasis of this section will rest with these sources. Dissolution patterns from these sources (Tables 17 and 18) were not found to be altered in the presence of soil.

Addition of soil to CSP, $SCSP_a$, and $SCSP_b$ pellets resulted in less P recovered from leachates than from those of pellets alone. For example, following 26 water leachings of a 1:2 mixture of $SCSP_b$ and Red Bay, it was found that 1,561 μg P/g soil were held in the soil. This amount of P retention was comparable to the 1,339 μg P/g soil P sorption maximum as previously defined by Langmuir equation for P rates up to 5000 μg/g of this soil.

Moderation of resultant acidity from both sources by soil presence was observed (Tables 16 and 17). After a 10-week period, acidity of CSP leachate with and without soil was 5.0 and 4.3, respectively. Under the same conditions, $SCSP_b$ leachate acidity was 3.4 and 2.9, respectively. As previously discussed, the finding that SCSP leachates were considerably more acid than those of CSP was also possibly from S oxidation, although this was not confirmed chemically.

Field Experiments

Phosphorus Sources, Rates, and Placements, 1971

Data were analyzed either with or without the first replication which had received a much higher rate of initial, non-phosphatic fertilization. Differences between analyses were not noted. Therefore, all

analyses presented (Appendix Table 46) are based on inclusion of all replications. Treatment means were adjusted to a mean stand level of 38 plants per plot except for check plots where lack of P fertilizer had a significant effect on stand.

Yield analyses

Since the experiment was a 5 x 3 factorial plus three additional treatments, analytical emphasis was placed on the factorial set of treatments which were 28 to 140 kg P/ha for each of the three P sources and two placements. Corn yield data are presented in Appendix Table 29. Corn yields showed response to be linear with increasing P rate (Appendix Table 46). Yield increased at an estimated rate of 199 kg/ha for each additional 28 kg P/ha (Fig. 6). Corn yields were alike for sources (Table 19) and placement, being 7936 and 7693 kg/ha for broadcast and row placements, respectively. The percentage of water-soluble P in the fertilizer, in agreement with studies by Webb and Pesek (1959), did not influence the effectiveness of broadcast and incorporated fertilizers for corn. Better plant growth was noted initially in plots with CSP, possibly due to more P and less acidity than from SCSP in the root environment, as shown in laboratory leaching studies. However, corn yields were alike from fertilization with various P sources. From these yields, inference was drawn that native P and P dissolved from SCSP later in the growing season were as efficient for yield production as amounts of P dissolved earlier from CSP. Although adequate corn yields from banded fertilizers were noted by Webb and Pesek (1958) to require that 60% of the applied P be in water-soluble form, the present study yielded no difference in corn yields between broadcast and band placement of soluble and less soluble P sources. Cultivation practices which partially mixed

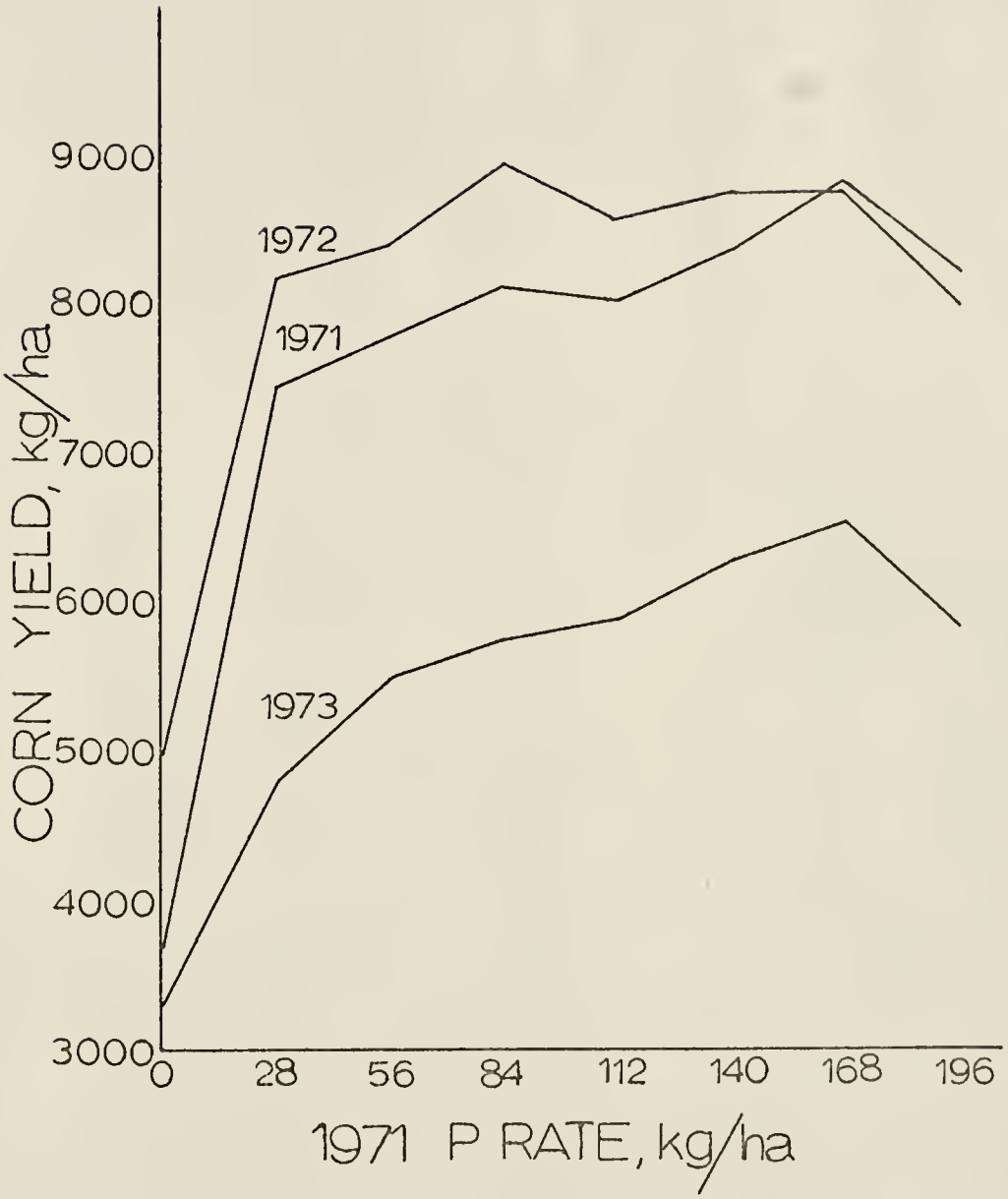

Fig. 6. Corn yields in 1971, 1972, and 1973 as influenced by P applied in 1971.

Table 19. Corn yields as affected by P sources and fertilizer placements

Source	P	Corn yield
	%	kg/ha
CSP	20.1	7930
$SCSP_a$	15.5	8020
$SCSP_b$	14.8	7780

the banded fertilizer and slow, but continual, dissolution of P from SCSP pellets could have affected the results of the present study.

Neither average ear weight nor kernel weight expressed as percentage of total ear weight showed differences for source, rate, or placement factors (Appendix Table 46). Average ear weight and percent kernel weight from check plots were 175 g and 77.9%, respectively, while those for other treatments averaged 231 g and 80.3%, respectively. Numbers of stalks, ears, and ears/stalk also were found lower in check plots compared to other plots. Check plots contained an average of 31 stalks, 26 ears, and 0.85 ears/stalk, while similar values from plots with applied P were 36, 36, and 1.03, respectively. Linear estimations for number of ears and ears/stalk are, respectively,

$$38.86 + 0.728R \qquad [10]$$

and

$$1.101 + 0.017R \qquad [11]$$

where R is P fertilization rate in kg/ha divided by 28.

Soil analysis

Phosphorus extracted from the soil sampled when corn was at the late-silking stage (Appendix Table 30) was not affected by rate, source, or placement, although an inconsistent rate x placement interaction was found (Appendix Table 46). To determine the effect of P rate on soil-P availability, the best regression relationships for each placement were estimated. For broadcast placement, a simple significant linear relationship was found, while a more complex relationship was determined for banded P fertilizer. These estimated equations are, respectively,

$$\text{Soil P} = 7.9669 + 0.7635R \qquad [12]$$

and

$$\text{Soil P} = -0.1671 + 16.9220R - 6.8546R^2 + 0.7840R^3 \qquad [13]$$

where R is P fertilization rate in kg/ha divided by 28. At low rates of P applied to this soil, Langmuir isotherms previously described soil-P retention as being linear. At higher rates of applied P, such as those which could be found in banded fertilization, P retention by Red Bay was observed to be non-linear. These observations made in the laboratory appeared to be related to those found to occur in the field under broadcast and banded P fertilizer situations.

Phosphorus extracted from the soil sampled at corn harvest time increased with rate and was higher in banded plots than in broadcast plots (Appendix Table 31). This observation was attributed to mode of sampling which attempted recovery of residual fertilizer pellets from banded plots. Though residual pellets were manually removed from soils prior to analysis, small fragments could have remained in the sieved samples. As was presented in the literature review, the reagent used (0.03N NH_4F in 0.1N HCl) has been shown to extract P from DCP, which was the primary form of P remaining in the pellets.

Fertilizer analysis

Cross sections of residual fertilizer pellets obtained after 6 months of cropping under field corn revealed a hollow appearance in CSP pellets, while less dissolution of SCSP pellets was suggested (Figs. 4 and 5). However, analysis of residual P in these pellets manifested essentially no difference between sources. Of initial P present in the pellets, 48.0% remained in CSP granules after 6 months in the field, while 52.0% of the initial P was found in the residual SCSP pellets. Consequently, although laboratory studies had shown an initially slower dissolution from SCSP than from CSP, the slower, but continual, disso-

Fig. 4. SCSP(1) and CSP(2) before field placement; SCSP(3) and CSP(4) 6 months after field placement (11.25x).

Fig. 5. SCSP(1) and CSP(2) before field placement SCSP(3) and CSP(4) 6 months after field placement (11.25x).

lution of P from SCSP over this period in the field was observed to release approximately the same percentage of P initially present as did CSP. Lack of corn yield response to P sources was attributed to this property. Evidently, a combination of native available P in Red Bay soil and slow dissolution of P from SCSP had been sufficient to produce yields equivalent to those on CSP plots. Hanway (1960) had noted that corn in Iowa would absorb 50% of the seasonal total of P by the time 25% of the seasonal total of dry matter had been accumulated. However, in this soil under the prevailing conditions previously described, P supplied to plants by large initial P release from CSP or by smaller but continual amounts of soluble P from SCSP gave similar corn yields.

Although percentage of initial P remaining in CSP and SCSP after 6 months in the field was about the same, X-ray diffraction analysis of these pellets revealed a difference in the form of compounds present. The MCP initially present in CSP and SCSP had been altered to less soluble compounds in both materials. However, after 6 months in the field, some MCP remained in SCSP granules, while none was found in CSP pellets. X-ray diffraction of CSP and SCSP pellets employed in laboratory leaching studies concurred with these results. Less soluble compounds found in both CSP and SCSP pellets taken from laboratory and field studies were found to be DCP, DCPA, monoclinic $Ca_2P_2O_7 \cdot 2H_2O$, monoclinic $Ca_2P_2O_7 \cdot 4H_2O$, OCP, and HAp. Four of these P compounds, DCPA, DCP, OCP, and HAp, have been documented by other workers (Lindsay et al., 1972) as being secondary forms of P fertilizers. Monoclinic $Ca_2P_2O_7 \cdot 2H_2O$ was noted by these workers to be a possible soil-fertilizer reaction product, while monoclinic $Ca_2P_2O_7 \cdot 4H_2O$ was observed to slowly alter to its orthorhombic form. Although quantitative determinations by X-ray diffraction were recognized to be difficult, relative peak size for CSP

residue appeared to possess more HAp than did SCSP. Since some of the initial MCP was found in SCSP pellets after 6 months, while none was noted in CSP pellets, greater quantities of HAp in CSP pellets than in SCSP were possible. Order of P alteration with time was noted by Lindsay and Taylor (1960) to be MCP -> DCP -> OCP -> HAp. Therefore, after 6 months in the field, SCSP residual pellets still contained some soluble P, while P remaining in CSP granules was noted to be in insoluble forms.

Approximately 15 residual pellets of each source had been crushed, ground, and sieved to 4 μ or less prior to powder mounting for X-ray diffraction. Pellets of SCSP prior to field placement were extremely hard throughout and difficult to cross-section. Those taken from the field were intact, but possessing soft interiors which were assumed to have occurred as a result of water vapor entrance into the pellet forming DCP and other compounds, with H_3PO_4 diffusing into the soil solution. Though all pellets employed for powder mounts had soft interiors, the possibility still exists that the coating of one or several pellets remained intact over the six-month period, thereby preventing water-vapor entrance and retaining the initial MCP. Should this possiblity have occurred, the MCP identified by X-ray diffraction would be due to that from intact pellets and not from pellets into which water vapor had entered.

Residual OSP pellets were observed in samples taken from the field; however, due to their extremely fragile condition, none afforded opportunity for removal from the soil. Results of diffraction of residual pellets of CSP and SCSP employed in laboratory studies had corroborated compound identification in residual pellets of the same material taken from the field. Therefore, residual granules of OSP employed in field

studies were assumed to contain the same compounds as did those of laboratory experiments. X-ray diffraction of residual OSP pellets after laboratory leaching revealed that the initially present MCP and $CaSO_4$ were altered to DCP and some $CaSO_4 \cdot 2H_2O$ with large quantities of $CaSO_4$ remaining.

Fertilizer pellets of any kind will initially present a low surface area for soil reactions. However, over the season, these pellets can be expected to be broken down by cultivation and weathering factors, thereby increasing soil-fertilizer contacts and subsequent reactions. Regardless of the presence of S-coating, approximately one-half of the P in CSP entered the soil during the first growing season and was subjected to these soil-P reactions.

Tissue analyses

Elemental analyses of P, Al, Fe, Ca, K, Mg, and Mn in corn plant tissue at both pre-silking and late-silking stages are presented in Appendix Tables 32-45. Also analyzed, but not presented in tabular form, were Zn and Cu in pre-silking tissue, and Si in late-silking tissue. Levels of tissue Zn ranged from 19 to 45 ppm, with an average value of 32 ppm. Tissue Cu concentrations averaged 10 ppm, ranging from 8 to 15 ppm. Contents of Si in tissue ranged from 0.370 to 0.705%, averaging 0.532%.

Rate and placement of the P fertilizers were found to have an effect on P content of corn plant tissue at both pre- and late-silking stages, while P sources had no effect (Appendix Table 46). Similar patterns of P concentration in tissue with increase in P rates were observed at both growth stages, although those at pre-silking were considerably higher than those at late-silking stage (Fig. 7). For both samplings, tissue P was

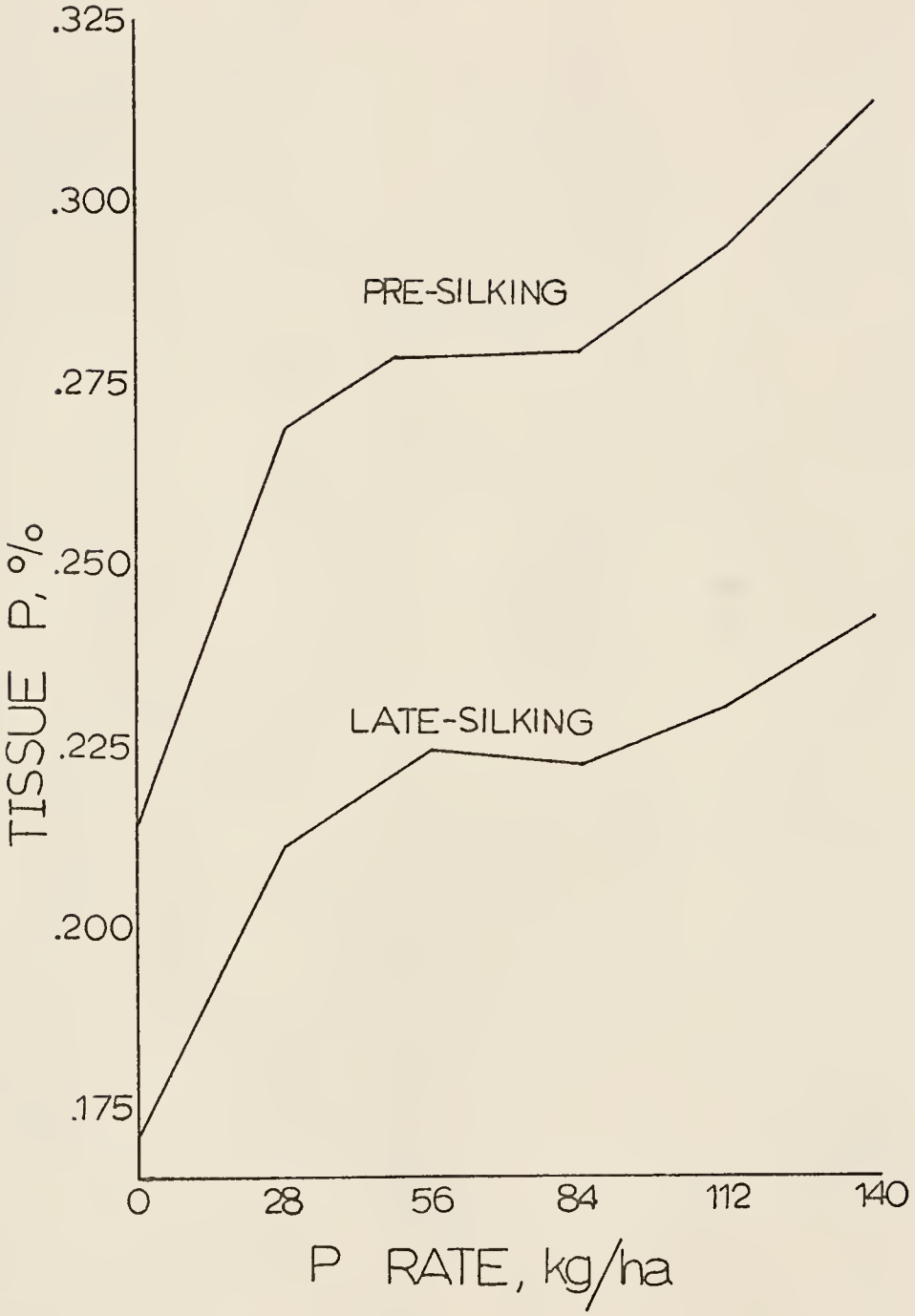

Fig. 7. Phosphorus content in corn plant tissue at pre- and late-silking stages as influenced by P rates.

found to increase linearly with rate, from 28 to 140 kg P/ha. At these rates, the estimated regression equation for tissue taken prior to silking is

$$P = 0.2854 + 0.0118R \qquad [14]$$

and for tissue at late silking is

$$P = 0.2300 + 0.0076R \qquad [15]$$

where R is P fertilization rate divided by 28. The almost horizontal portions of the curves between 56 and 84 kg P/ha were considered unusual in that other workers had not observed this type of curve with P uptake by corn. Phosphate-sorption maximum of Red Bay soil was defined by Langmuir equation as being 150 μg P/g soil or 84 kg P/ha. Once this amount of P was applied, the slope of P uptake curves was observed to approach that of the 0-56 kg P/ha portion of the curve.

Phosphorus in pre-silking tissue was significantly higher when fertilizer was banded (0.296%) rather than broadcast (0.277%). In tissue sampled at late-silking stage, the opposite was found, namely 0.217% P for banded, 0.234% P for broadcast fertilizer. Since late-silking tissue was sampled a month after pre-silking tissue, these differences were attributed to increased proliferation of young plant roots that enabled the plants to make better use of the broadcast P fertilizer.

Correlations of yield, soil, and tissue analyses

Linear correlations (Appendix Table 47) of corn yields with soil P sampled at late-silking and harvest times and with tissue P at pre- and late silking were determined in two ways: 1) using the four lowest P rates, and 2) using all available data. For the latter data set, multiple correlations involving the quadratic P model were also estimated. However, multiple correlation coefficients were considered significant

only when addition of the quadratic term in the P model resulted in a significant improvement in the relationship with the dependent variable, in this case, corn yields. From the above analyses, only tissue-P content at late-silking stage was correlated with yields. However, since only 7% of yield variation was accounted for by variations in this tissue P either at the first four rates or over all rates, this parameter was not the main one affecting yields.

Correlations of other tissue elements with yield and tissue P were estimated (Appendix Table 47). Yields were negatively correlated with Al in tissue sampled at pre-silking stage and positively correlated with Ca in tissue sampled at late-silking tissue. However, these significant correlations provided poor accounts (3%) of variation in yield. Linear correlations between P in pre-silking tissue and Ca, Mg, K, and Zn in the same tissue were found; K accounted for 50% of the variation in P, while Ca, Mg, and Zn accounted for much lesser variations in P content. Phosphorus concentration in tissue sampled at late-silking stage was correlated negatively with Al and Fe and positively with P, K, and Mn in pre-silking tissue. Content of P in late-silking tissue was correlated negatively with Al and Si and positively with Ca in the same tissue. None of the independent variables explained more than 17% of the variation in tissue P at this growth stage. Inclusion of the quadratic term in the equation to give curvilinear correlations revealed that P concentration in pre-silking tissue was correlated with Ca, Mg, and Mn in the same tissue, and that P content of corn ear-leaf tissue at late silking was correlated with Al in the same tissue. As previously discussed, nutrient concentrations in plant tissue did not accurately account for variation in P concentrations.

Fertilization with Mixtures of Coated and Non-coated Phosphorus Fertilizers 1971

As for the preceding field study of 1971, all analyses presented (Appendix Table 65) are based on inclusion of the four replicates, since differences between analyses with and without data of the first replication were not found.

Yield analyses

Corn yield data are presented in Appendix Table 48. Neither corn yields nor kernel weight as a percentage of total ear weight showed a difference between uncoated CSP and OSP used in the fertilizer mixture (Appendix Table 65). Only corn yield responded to percentage of SCSP in the fertilizer mixture. Corn yield followed the cubic relationship

$$\text{Yield} = 8131 + 934.6X - 555.9X^2 + 76.67X^3 \qquad [16]$$

where X is percentage of SCSP divided by 20. Based on this relationship, it was estimated that yield was maximized using either 24 or 100% SCSP, while the response was a minimum at 73% SCSP in the fertilizer mixture. It was postulated that, where minimum yield response was obtained, the 27% or 12.7 kg P/ha supplied by uncoated P fertilizer was rendered unavailable by soil components, whereas the slow and continual dissolution at 73% SCSP was insufficient for corn plants. Where response was maximized, it was hypothesized that from the 66:24 uncoated to coated P fertilizer mixture, the immediately soluble 55 kg P/ha from uncoated fertilizer plus the continual dissolution of 29 kg P/ha from SCSP combined to adequately support plant growth. Maximum yields from continual dissolution of 84 kg P/ha as SCSP was attributed to P availability being maintained at an optimal level for corn plants.

Number of ears and ears/stalk were greater when OSP rather than CSP

was employed (Appendix Table 65). The observation that OSP plots contained an average of 39.3 ears and 1.057 ears/stalk while CSP had 37.3 and 1.008, respectively, was offset by the lower average ear weight produced on soil receiving OSP (234 vs 239 g). Consequently, no difference in corn yields between the two sources was noted.

Soil and tissue analyses

Soil P extracted from soil sampled when corn was at late-silking stage (Appendix Table 49) was neither affected by percentage of SCSP in the fertilizer nor by the source of uncoated fertilizer used (Appendix Table 65). Phosphorus extracted from soil sampled at corn harvest followed no discernible relationship with treatment (Appendix Table 50).

Elemental analyses of P, Al, Fe, Ca, K, Mg, and Mn in corn plant tissue at both pre-silking and late-silking stages are presented in Appendix Tables 51-64. Also analyzed, but not presented in tabular form, were Zn and Cu in pre-silking tissue, and Si in late-silking tissue. Levels of tissue Zn ranged from 20 to 44 ppm, with an average value of 29 ppm. Tissue Cu concentrations averaged 9 ppm, ranging from 8 to 14 ppm. Contents of Si in corn ear-leaf tissue ranged from 0.365 to 0.565%, averaging 0.443%.

Phosphorus concentrations in both pre- and late-silking tissue were affected by the percentage of SCSP in the mixture, while neither was affected by uncoated P sources (Appendix Table 65). In pre-silking tissue, P concentrations increased linearly according to the relationship

$$P = 0.2339 + 0.0084R \qquad [17]$$

where R is percentage of SCSP divided by 20. Such a simple relationship with P in tissue sampled at late silking was not observed with the

estimated equation being quintic.

Correlations of yield, soil, and tissue analyses

Correlations were made between yield and soil P sampled both at late silking and at harvest, and between yield and tissue P at pre- and late-silking stages (Appendix Table 66). The curvilinear correlation between P extracted from soils sampled at harvest time and yield was significant ($r = 0.4334$), but accounted for only 18% of the yield variation. The linear correlation between yield and P concentration in pre-silking tissue ($r = 0.3322$) was significant (Appendix Table 66). Addition of the quadratic term did significantly improve the correlation between P content of tissue sampled at the late-silking stage and yield ($r = 0.3807$). However, as in the previous study, neither soil nor tissue P accounted for greater than 20% of the yield variation.

Calcium concentration in pre-silking tissue was correlated with yield, while K and Cu were correlated with P in this tissue (Appendix Table 66). Addition of the quadratic term revealed P concentration in pre-silking tissue to be correlated with P content of tissue sampled a month later. These significant factors accounted for less than 20% of variation in the P content.

Phosphorus Sources, Rates, and Placements, 1972

Yield analyses

The responses analyzed were percent kernel weight, average ear weight, and yield (Appendix Table 84). Corn yield data are given in Appendix Table 68. Only yield was affected significantly by rate of P fertilization. The yield response increased linearly at an estimated rate of 126 kg/ha per additional 14 kg P/ha applied (Fig. 6). Lack

of any yield response to P source agreed with the results of the previous year that there was no plant response to different rates of P dissolution from CSP and SCSP. A decrease due to additional fertilization was found for average ear weight. Plants grown on plots with residual P only had a higher average ear weight (234 g) than did those refertilized with P (227 g).

That corn yields manifested no advantage of refertilization confirmed the conclusion of Kamprath (1967) that P added to an Ultisol was not lost irreversibly, but was available for plant growth in subsequent years. Using Red Bay soil, Robertson et al. (1966) found no significant differences in corn yields after 4 years from various residual P plots. Following a large initial application of CSP, these workers annually added 15 or 29 kg P/ha. However, the lowest rate of CSP initially applied was 123 kg P/ha, while the lowest rate of the present study was 28 kg P/ha. Singh, Martens, and Obenshain (1966) used low P applications in a greenhouse experiment with a kaolinitic Rhodic Paleudult. These workers found that residual P from an annual application of 23.5 kg P/ha was adequate to supply the P requirement of 3 successive crops of alfalfa.

By application of P almost equal to the Langmuir defined P-sorption maxima of 719 kg P/ha of a Typic Hapludult, Kamprath (1967) found that adequate P for 8 years was supplied for plant growth. The present study included rates less than, equal to, and greater than the Psm of this soil as defined by the Langmuir equation. When rates equivalent to this Psm were applied in 1971, the highest 1972 yield from residual P was found (Fig. 6). On a Typic Paleudult with a Psm one-third that of the Rhodic Paleudult in the present study, Woodruff and Kamprath (1965)

found that P applications had to equal Psm level to obtain maximum yields. Such was the case in the present study as indicated by Fig. 6. On the Typic Paleudult described by Fox and Kamprath (1970), 2 years of response to residual P were reported where initial P applied was equivalent to Psm.

Overall higher yields obtained in 1972 compared to those of 1971 were attributed to use in 1972 of both a higher yielding variety and irrigation. Kernel weight as percentage of total ear weight of the variety employed in 1971, 'Pioneer' 3009B, averaged 80.2%, while that of 'Pioneer' 3369A, the 1972 variety, was 85.4%.

Soil analyses

Phosphorus extracted by 0.03N NH_4F in 0.1N HCl from soils sampled 12 months after 1971 band placement of P fertilizer generally increased from lower to higher P rates (Appendix Table 69). In soils sampled when corn was at late-silking stage, P extracted by both 0.03N NH_4F in 0.1N HCl and 1N NH_4OAc (pH 4.8) generally increased with rate and additional fertilization in 1972 (Appendix Tables 70 and 71). The fact that P extracted by the former reagent usually exceeded by 20 times P extracted by the latter reagent was attributed to the relative greater extracting strength of the ammonium fluoride reagent for Al-P compounds and DCP.

The pH values and Ca, K, and Mg extracted by 1N NH_4OAc (pH 4.8) from soils sampled when corn was at late-silking stage are presented in Appendix Tables 73-76. Over all plots, the same soil pH of 5.5 was usually found. This increase above the pH of 5.1 recorded the preceding year was due to reaction of previously applied dolomite with the soil. Only soil Ca contents increased with additional P fertilization in 1972, while soil levels of K and Mg decreased. This same trend occurred in corn

ear-leaf tissue sampled at the same time (Appendix Tables 80-82) and was ascribed to the fact that Ca was the accompanying cation in the applied P fertilizer and to the well-recognized antagonism between Ca, K, and Mg.

Available P content in soils sampled when plants were at late-silking stage (Appendix Table 70) and at harvest (Appendix Table 72), upon statistical analysis, presented a complex picture (Appendix Table 84). Refertilized plots contained 91.7 μg P/g soil compared to 13.2 μg P/g soil from residual P plots sampled in June. Corresponding values in August were 68.6 and 9.6 μg P/g soil. However, yields had not been found to be affected by additional fertilization. Implication was that soil-P levels of residual plots, though lower than those of refertilized plots, contained sufficient P to produce yields equal to those of refertilized plots. For both soil responses, plots fertilized with $SCSP_a$ were found to contain a significantly lower P content than those with CSP or $SCSP_b$ (Table 20). Since difference in soil P among sources was not manifested by tissue P or yield, inference was drawn that soil P present in all plots from various sources was at or beyond the level needed for plant growth and maximum yield production. Though not significantly different, 1971 soil P sampled at corn silking time projected more P present in $SCSP_a$ plots than from the other sources. Apparently, dissolution of $SCSP_a$ pellets was at a faster rate in the field than that of CSP or $SCSP_b$. In laboratory leaching studies of 26-week duration, the percentage of P dissolved from CSP, $SCSP_a$, and $SCSP_b$ was respectively 71.8, 53.7, and 46.0% of the amount present. However, various batches of $SCSP_a$ revealed poor duplication of results, showing from 39.7 to 90.2% of P present in the pellet to be recovered in the leachates.

Rate of P fertilization was observed to affect soil-P levels in

Table 20. Phosphorus extracted in 1972 and in 1971 by 0.03N NH_4F in 0.1N HCl from plots receiving three P sources

Source	Content P	Soil P, 1972*		Soil P, 1971*
		Silking	Harvest	Silking
	%	μg P/g soil		
CSP	20.1	53.6a	44.2a	9.43a
$SCSP_a$	15.6	46.0b	31.6b	10.33a
$SCSP_b$	14.8	57.8a	41.5a	8.01a

* Values are means of all rates and those in each column not followed by the same letter are significantly different.

both samplings (Fig. 8). Since yields were maximized for the combination of the 1972 rate of 42 kg P/ha plus the 1971 rate of 84 kg/ha, additional P fertilization was judged to be superfluous. For soil responses in both samplings, the second order interaction of fertilization x source x rate was significant. This implied that the joint effect of source and rate depended on whether or not refertilization had occurred. In both samplings, the same basic trend (Table 21) was that neither sources nor rates of P fertilization had any effect on P present in residual plots. Phosphorus concentration in refertilized soils sampled at harvest again indicated greater dissolution from $SCSP_a$ than from either CSP or $SCSP_b$ (Table 21). Rate x source interaction of residual plots revealed that significant relationships existed, though some were complex (Table 22). Where simple relationships were found, equations are presented; otherwise, only the degree of relationship is indicated.

As previously discussed, dissolution from $SCSP_a$ and CSP exceeded that from $SCSP_b$. It appears significant that the slower the dissolution, the more simple was the rate x source relationship 15 months after application. At 18 months following application, the more slowly dissolving P source, $SCSP_b$, followed a more complex relationship, while a linear rate x source relationship was noted for the more rapidly dissolving compounds.

Tissue analyses

Elemental analyses of P, Al, Fe, Ca, K, Mg, and Mn in corn plant tissue at late-silking stage are presented in Appendix Tables 77-83. The only factor that affected P concentration in tissue sampled at late-silking stage was additional P fertilization (Appendix Table 84). Plant tissue from plots refertilized in 1972 contained significantly more P

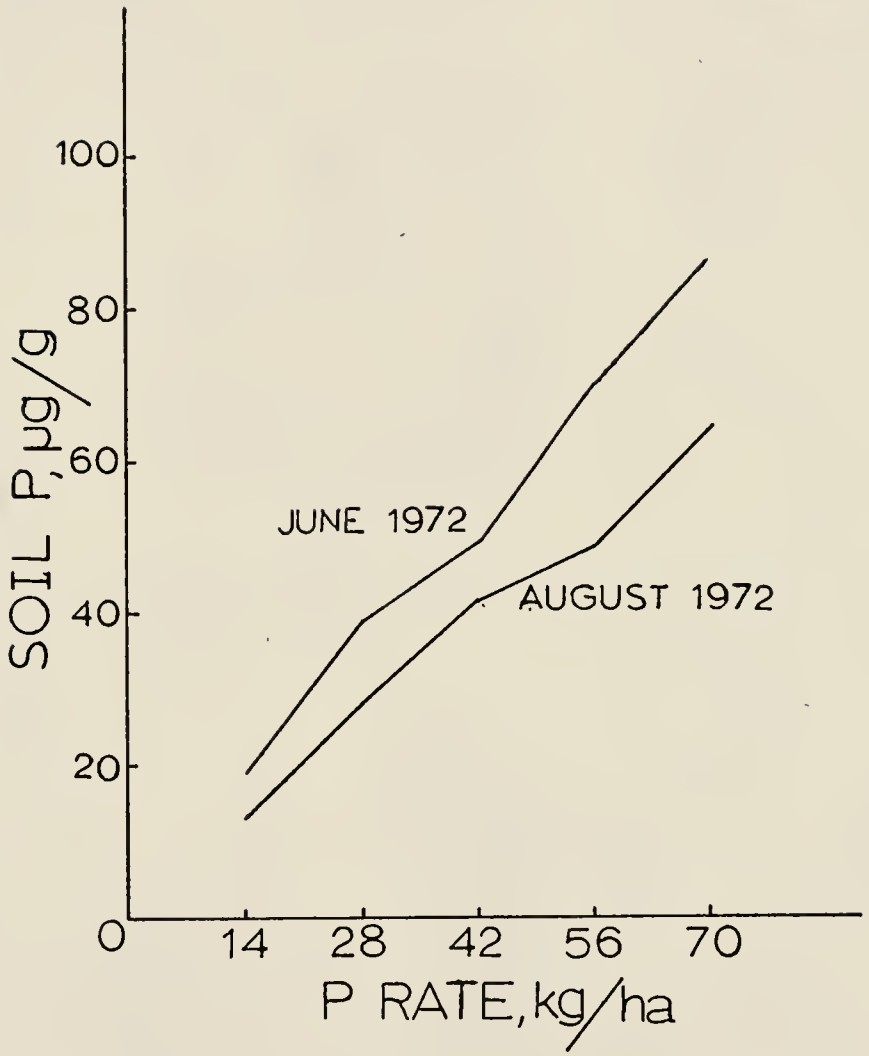

Fig. 8. Phosphorus content in soil at two dates as affected by P rates.

Table 21. Fertilization x source x rate interaction influence on soil P levels from refertilized and residual plots sampled at two dates

Fertilization year	Source	P rate, 1971* 28	56	84	112	140
		µg P/g soil				
		Sampled at pre-silking stage				
1971 and 1972†	CSP	28.4a	63.1a	80.2ab	104.8b	194.8a
	$SCSP_a$	34.2a	69.5a	61.1b	131.0a	99.5b
	$SCSP_b$	27.4a	69.5a	100.8a	135.0a	179.8a
1971	CSP	11.1a	8.3a	20.7a	16.1a	11.8a
	$SCSP_a$	7.8a	9.9a	17.8a	15.4a	14.1a
	$SCSP_b$	8.4a	13.8a	13.3a	14.2a	15.8a
		Sampled at corn harvest				
1971 and 1972†	CSP	23.1a	59.4a	81.3a	106.9a	124.5a
	$SCSP_a$	10.6b	49.6ab	50.2b	71.4b	84.6b
	$SCSP_b$	23.4a	35.8b	88.9a	78.1b	141.0a
1971	CSP	9.0a	8.2a	9.4a	10.8a	9.4a
	$SCSP_a$	8.0a	8.6a	11.6a	9.6a	12.2a
	$SCSP_b$	5.9a	7.8a	7.6a	13.8a	12.4a

* All values in each interaction group column, when not significantly different, have the same letter.

† Fertilization rates in 1972 were one-half those of 1972.

Table 22. Rate x source relationships as defined by soil P sampled from one-year residual plots at two sampling dates

Source	Soil P, June	Soil P, August
CSP	Cubic	28.0308 + 4.3148R*
$SCSP_a$	Quartic	19.0232 + 2.6068R
$SCSP_b$	41.4646 - 9.6152R*	Quartic

* R is 1971 P fertilization rate divided by 28

(0.313% P) than those of residual plots (0.298% P). However, the higher P content of plants on refertilized plots did not result in higher yields than those obtained from residual plots.

Correlations of yield, soil, and tissue analyses

Phosphorus content in soils which remained as residual plots in 1972 and were sampled prior to fertilization was significantly correlated both linearly and curvilinearly with yield (Appendix Table 85). However, corn yield variation explained by this soil P barely exceeded 21%. Corn yields were linearly correlated with available P in soils sampled when plants were silking and at harvest. These effects were noted when either the first four or all rates were used in the equation. Again, these factors accounted for less than 12% of corn yield variation.

Phosphorus concentration in corn ear leaves sampled in 1972 at late silking were linearly ($r = 0.5753$) and curvilinearly ($r = 0.6568$) correlated with 1972 corn yield (Appendix Table 85). With the multiple regression equation, 44% of the corn yield variation was explained by tissue-P content. Calcium level in these tissues was correlated linearly with corn yield ($r = 0.4501$). Tissue Ca also was correlated both linearly ($r = 0.5889$) and curvilinearly ($r = 0.6146$) with tissue-P content. These correlations were not entirely unexpected, as Ca was the accompanying cation in P fertilizers used. Correlations between tissue concentrations of Fe, K, and Mn with tissue P at late-silking stage were noted, but contributed only slightly to tissue P variability.

Various Combinations of Coated and Non-coated Fertilizers with and without Strip Mulch, 1972

Yield analyses

Kernel weight as percentage of total ear weight, average ear weight,

and yield were not affected by any of the treatment combinations (Appendix Tables 86 and 96). Plastic mulch has been used customarily in sandy soils to curtail leaching losses and evaporation (Hayslip and Iley, 1966). Sulfur-coated urea and KCl also have proved successful in reducing N and K leaching from sandy soils (Locascio and Fiskell, 1970). Plastic mulch and S-coated fertilizers supplied no additional advantage over conventional fertilizer in Red Bay soil because leaching losses were apparently minimal.

Soil analysis

The only experimental factor found to affect available-P content of soils sampled when corn was at the late-silking stage was P source (Appendix Tables 87 and 96). The fact that use of SCSP significantly reduced soil-P levels (89.9 μg P/g soil) as compared to CSP (115.5 μg P/g) was attributed to slower dissolution of SCSP materials.

All four experimental factors, N, P, and K sources and plastic mulch, were observed to have an effect on soil P levels determined in samples taken at harvest time (Appendix Tables 88 and 96). Use of SCSP again reduced recovered P from the soil as compared with CSP (78 vs. 140 μg P/g soil). When either S-Urea, S-KCl, or plastic strip mulch was used, extractable soil P decreased from 118 to 100 μg P/g soil. However, the nature of these factors was complex as indicated by two significant second-order interactions. These were P source x N source x K source and P source x K source x mulch. The means for these interactions are not presented, since, again, the only distinguishable result was that use of SCSP reduced recovered soil P in each case.

Table 23. Phosphorus concentration in late-silking tissue as affected by interactions of P source x N source and K source x N source

Variable source	N source	
	Urea	S-Urea
	----- P, % -------	
CSP	0.303	0.286
SCSP	0.285	0.305
KCl	0.293	0.279
SKCl	0.295	0.313

Tissue analyses

Elemental analyses of P, Al, Fe, Ca, K, Mg, and Mn in corn plant tissue at late-silking stage are presented in Appendix Tables 89-95. Tissue P at late-silking was affected by all four experimental factors (Appendix Table 96). Only the effect of mulch, however, was independent of the other effects; and its use significantly decreased tissue-P concentration. Phosphorus content of the tissue when mulch was used was 0.285%, while that without mulch was 0.305%. The effect of urea source on P-tissue concentration depended on both the P and K sources (Table 23). For plots with urea, maximum tissue-P content was obtained when N and P sources both were uncoated or when both were coated. Presence of both S-KCl with S-Urea also increased the tissue-P concentration.

Correlations of yield, soil, and tissue analyses

No correlation between yields and any of the soil or tissue variables was found (Appendix Table 97). Phosphorus in corn ear-leaf tissue sampled at late silking was correlated linearly with tissue K and curvilinearly with tissue Ca. However, as in previous correlations among elements in plant tissue, these relationships provided poor accounting 23.1 and 12.2%, respectively, of variation in tissue P.

Evaluation in 1973 of Residual Phosphorus from Previous Two Years

Yield, soil, and tissue analyses

In 1973 an evaluation of residual P effects on corn yields and on soil and tissue P levels was made. Yield, soil P, tissue P, Al, and Fe data, and the analyses of variance are presented in Appendix Tables 99-104. Samples from plots which received additional P in 1972 showed higher corn yields in 1973, higher P levels in both soil sampled prior

to the 1973 planting and in tissue P sampled at the late-silking stage than did plots which received P fertilizer only in 1971 (Table 24). Thus, the observed lack of response to additional fertilization in 1972 did not carry over into 1973. This meant that P levels in Red Bay soil were sufficient to produce yields equal to those of refertilized plots for one, but not two, years.

Furthermore, each response linearly increased with rate (Fig. 9). The estimated equations for tissue P and corn yield are, respectively,

$$P = 0.2405 + 0.0284R \quad [18]$$

$$Y = 4201.2 + 480.76R \quad [19]$$

where R is the 1972 P fertilization rate divided by 14. Since no significant interactions were detected for either tissue P or yield, the implication was that this rate effect was similar both for 1971 and 1972 treatments.

However, for P content of soil sampled prior to planting, the effects of the experimental factors were dependent on each other (Appendix Table 104). The second-order interaction of fertilization x rate x source was found to be significant (Table 25). In this case, an effect of source at the highest common rate was detected even from plots not fertilized since 1971. While there was a general depression of soil-P content due to length of time since fertilization, the decrease was not statistically significant. Soil P relationships from rate x source interaction as influenced by previous fertilization dates are presented in Table 26. Where relationships were simple, equations are given; otherwise, only the degree of relationship is indicated.

The yield, tissue P, Al, and Fe data of the continuation of the 1971 study involving various combinations of coated and non-coated P fertilizers,

Table 24. Phosphorus concentrations in soil and in tissue, and corn yields in 1973 on 1-and 2-year residual P plots

Previous P fertilization	Response variables in 1973*		
	Soil P	Tissue P	Yield
Year	µg/g soil	%	kg/ha
1972	15.5a	0.269a	5980a
1971	11.3b	0.249b	5310b

* All column values not followed by same letter are statistically different (0.01).

Table 25. Soil-P levels prior to 1973 planting in a study of one- and two-year residual P

Previous P fertilization	Source	P rate, 1972*				
		14	28	42	56	72
---- Year ----		---------- kg/ha ----------				
1971† and 1972	CSP	13.7a	14.4a	15.6a	21.1a	22.3ab
	$SCSP_a$	7.4b	11.3a	10.8a	20.6ab	19.7b
	$SCSP_b$	6.7b	9.9a	16.0a	15.3b	27.3a
1971†	CSP	5.9a	7.2a	13.8a	12.5a	9.9b
	$SCSP_a$	6.3a	8.7a	12.1a	14.0a	22.6a
	$SCSP_b$	6.2a	11.8a	10.4a	12.1a	15.3b

*All column values in each interaction group statistically alike have the same letter.

†Fertilization rates in 1971 were twice those of 1972.

Table 26. Soil P relationships for P rate x P as source interaction for residual P from 1971 and 1972

Source	Soil P relationships	
	1971	1972
CSP	Cubic	11.4856 + 2.6824R*
$SCSP_a$	1.4818 + 1.4818R	Quartic
$SCSP_b$	6.2916 + 2.0692R	1.1424 + 5.2304R

* R is 1972 P fertilization rate divided by 14.

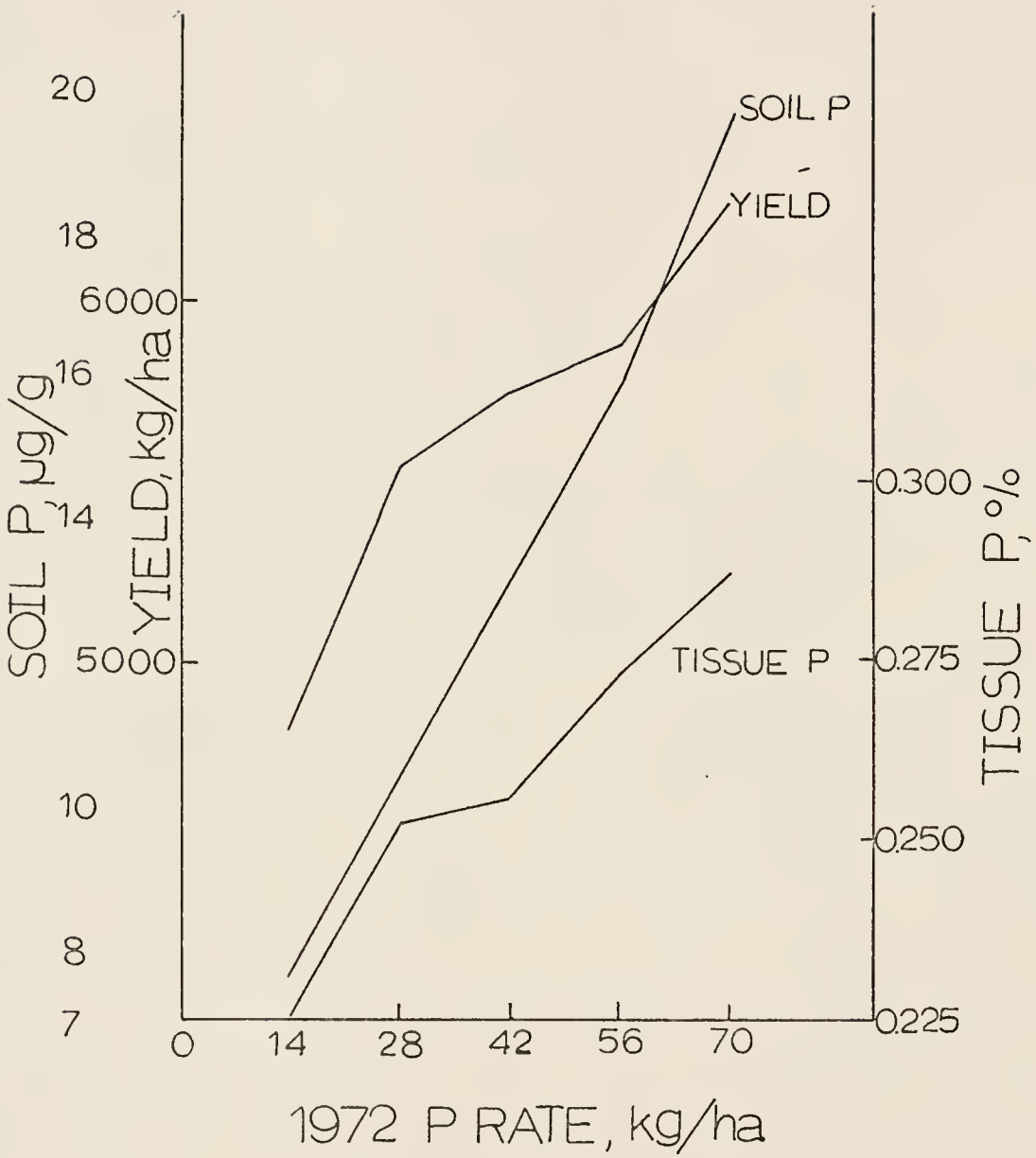

Fig. 9. Response of 1973 P concentrations in soil and tissue and corn yield as influenced by 1972 P rates.

herein referred to as experiment 6, are presented in Appendix Tables 106-109. Analyses of tissue-P content and yield both exhibited significant differences due to the percentage of SCSP used in the fertilizer mixture (Appendix Table 110). In both cases, the relationship was complex, being cubic for yield and quartic for P concentration in corn ear-leaf tissue sampled at the late-silking stage. Minimum tissue-P levels (0.244% P) and yields (5910 kg/ha) were found when percentage of SCSP in the mixture was 20%. This finding was considered significant in that this was the same percentage of SCSP which, 2 years previously, was observed to produce near maximum P-tissue levels (0.2272) and maximum yields (8530 kg/ha). Also, the mixture which 2 years previously had resulted in both minimum P-tissue levels (0.215% P) and yields (7800 kg/ha) was noted in 1973 to have near maximum P-tissue levels (0.271%) and maximum yields (7590 kg/ha). The 1971 mixture with a high percentage (80% uncoated P fertilizer) of its P as immediately soluble material was sufficient to produce maximum yields during that growing season, but not 2 years later. The opposite was true of the mixture with a low percentage (20%) of uncoated or immediately soluble P.

Correlations of yields, soil and tissue analyses

Phosphorus levels in soils from experiment 5 sampled prior to planting were found to be correlated significantly with yields using linear correlations for the first four P rates ($r = 0.4813$), or with all P rates ($r = 0.5065$), and by inclusion of the quadratic term ($r = 0.5872$) (Appendix Table 105). Though significance was exhibited in these correlations, none accounted for greater than 35% of the yield variation. However, these correlations were observed to be higher than any of those obtained for similar comparisons the previous 2 years. This

observation possibly was due to these soil samples being kept at field moisture prior to analysis, while previous samples had been air-dried prior to analysis to facilitate removal of residual fertilizer P pellets. The improved correlations could be due also to the longer time of equilibration following fertilization which the soils had in 1973 as compared to those in 1971 and 1972. All other soil samplings, with one exception, had been taken 3 and 6 months following fertilization. The 1973 samples were taken a year after the last fertilization. A third possible contributing factor was the occurrence of more complete mixing of P fertilizer within the plots themselves. With the increased equilibration time following fertilization, three vs. two and one years, it is likely that by cultivation processes the residual P fertilizer was better mixed with the soil over the extended time period, thereby contributing to a more uniform level of P per plot.

Tissue-P concentrations at the late-silking stage from experiment 5 also were found to be correlated significantly with yields using linear correlations either for the first four P rates ($r = 0.7344$), or with all rates ($r = 0.6998$), and curvilinearly ($r = 0.7425$) (Appendix Table 104). One-half of the yield variation, on the average, was accounted for by these tissue-P levels. The above correlations also were noted to be improvements for tissue-P correlations with yield over those found the previous years. Better mixing of fertilizer P with soil and greater equilibration time following fertilization possibly were the factors controlling the improved correlations for soil P and yield. It is conceivable that these two factors also contributed to plant uptake as shown by the improved correlations between tissue P and yield.

Phosphorus content of tissue at the late-silking stage from experi-

ment 6 also was noted to be linearly ($r = 0.2244$) and curvilinearly ($r = 0.3989$) correlated with yield (Appendix Table 111). However, no more than 16% of the yield variation was explained by these tissue-P levels. Neither Al nor Fe in plant tissue of experiments 5 and 6 was observed to be correlated with P concentrations in the same tissue or with yields.

Better correlations between yields and P content of corn ear-leaf tissue at the late-silking stage were observed in all three years where a wide range of tissue-P levels and yields existed, such as in experiment 5, rather than where narrow ranges were found, such as in experiment 6. The wide ranges had been produced by various rates of P fertilization, while the narrow range was produced by the same rates of P fertilization. It is suggested, therefore, that any attempt to employ tissue-P data in a fertility evaluation program will enjoy greater success if tissue is obtained from plants fertilized at various P levels.

Available P in virgin Red Bay fsl was estimated by 0.03N NH_4F in 0.1N HCl to be 12-13 kg P/ha. To produce corn yield of 7730 kg/ha, a minimum of 27 kg of available P/ha is required (Sprague, 1964). Of this amount, 18 kg P/ha are removed in the grain yield, while 9 kg P/ha are returned to the soil when stalks are incorporated. Therefore, based on this estimation of the available P in Red Bay soil, unfertilized plots would be expected to average yields of 3430-3710 kg/ha. Actually, check plots averaged 3790, 4990, and 3310 kg/ha in 1971, 1972, and 1973, respectively. Irrigation was employed only in 1972. However, it will be recalled that estimations of yield variation in fertilized plots by available soil-P levels did not exceed 36% in any of the field experiments.

Yield responses to residual P were evident in both 1972 and 1973 (Fig. 6). In 1972, the greatest yield was on plots fertilized in 1971 with 84 kg P/ha. In 1973, the highest yield was on plots which had received 168 kg P/ha in 1971. From these results, the implication was drawn that residual P at the rate of 84 kg P/ha was sufficient to produce high yields for one, but not two, years. Residual P resulting from the rate of 168 kg P/ha was required to produce high yields for two years.

The previously discussed soil- and tissue-P levels and corn yields of 1971, 1972, and 1973 as influenced by P applications of the first 2 years are presented in Appendix Table 112. Since field experimental design precluded use of check plots and the two highest P rates in statistical analysis of the data, the data of these three treatments cannot be compared statistically with data of the other treatments. However, from Appendix Table 112, certain observations can be made. Soil-P levels over all 3 years generally increased with P rate. Tissue-P content in all 3 years was maximum in plants from plots receiving 168 kg P/ha in 1971. In both 1971 and 1973, the rate of 168 kg P/ha produced the highest corn yields. These 2 years were those which received no irrigation. In 1972, when the experiment received irrigation, near maximum corn yields were obtained on plots which in 1971 had received 168 kg P/ha, while maximum yields were taken from plots to which were applied 84 kg P/ha in 1971.

Correlations Between Experiments

In an attempt to determine whether P concentrations in tissue sampled at late-silking stage could aid in predictions of yields the following year, regression estimates also were made using the appropriate 1971, 1972, and 1973 data (Table 27). All correlations between tissue-

Table 27. Correlations between various combinations of tissue-P levels in one year and yields of another year

Year variable		Regression r values		
Tissue P	Yield	Linear		Multiple for all rates
		First 4 rates	All rates	
1971	1972	0.2769*	0.4545**	0.5169**
1972	1973	0.7382**	0.6968**	0.7260**
1972	1971	-0.1162	0.2209**	0.2856**
1973	1972	0.5275**	0.4363**	0.5324**

*Significant at 0.05 level.

**Significant at 0.01 level.

P concentrations for the first year and yields obtained the following year were found to be significant, with multiple correlations generally being greater than the linear ones. The correlations of this study were higher than those of other studies which used tissue-P levels and yields for the same year. Even when fertilization was applied in 1972, 1971 tissue-P levels were correlated with 1972 yields, though this explanation of yield variation did not exceed 27%. When no additional fertilization was applied in 1973, tissue-P levels in 1972 accounted for up to 54% of the yield variation in 1973. The implication here was that this technique may be more useful with residual P studies than where additional fertilization will be made the following year.

However, when current tissue-P levels were correlated with yields of the preceding year, significance again was found, although none of the P levels accounted for more than 28% of the yield variation. This percentage was nearly equivalent to that obtained for yield variation when 1972 yield was regressed against 1971 tissue P levels.

SUMMARY AND CONCLUSIONS

This investigation was designed to provide selected pertinent information on fertilizer-P retention and availability in an agriculturally important soil of high P-retention capacity. Laboratory and field research included characterization and components of P retention in Red Bay fsl. Another phase of research was the comparison of SCSP, CSP, and OSP as P sources for field corn. This phase led to an evaluation of these sources on soil-P availability and on corn responses, first to current and later to residual rates of application.

Sorption of applied P ranging from 10 to 5,000 μg/g soil by Red Bay fsl at 1, 72, and 144 hours was investigated using four methods. This P sorption over all rates and times was best described (R^2 = 99.7%) by use of a rearrangement of the parabolic equation with inclusion of a square-root term as described by Gunary (1970). Estimation of P sorption by the Freundlich equation was best (R^2 = 99.8%) at higher P rates, 500-5,000 μg/g soil, with the longest equilibrium time. The Langmuir equation better described P sorption (R^2 = 99.8%) at low P rates, 10-150 μg/g soil, with the shortest equilibrium time. Phosphate potential as a method also accurately defined P sorption (R^2 = 99.1%) at the low rates of applied P and shortest equilibrium time. Removal of organic matter and amorphous aluminosilicates had little effect on P retention by this soil. However, removal of crystalline Fe and Al by CDB reduced P sorption by 89%.

Phosphorus dissolution from CSP was retarded by use of S-coating; however, observation of wide variance in P released from SCSP pellets was noted in both laboratory and field studies. Soil moderated acidity of leachate by one-half of a pH unit from various P sources. Soil sorption of P dissolving from fertilizer granules (1,340 μg P/g soil) was comparable to P-sorption maximum as described by Langmuir equation (1,560 μg P/g soil) for P rates up to 5,000 μg/g soil. Residual pellets of SCSP and CSP were examined after 6 months under field corn and both contained approximately 50% of the initial P. Most of the P within the pellets was in the DCP and DCPA forms. However, in residual pellets of SCSP some MCP remained, while in those of CSP all MCP had been altered to less soluble compounds.

Corn yields in 1971 were alike between SCSP and CSP sources, and for broadcast and band placements. Yields increased linearly with increasing P rates up to 140 kg/ha. Inference from this and subsequent studies was that P supplied to plants either in an immediately soluble form or in small, but continual, amounts of soluble P were equally effective for corn. Available soil P was linearly related to P rate when fertilizer P was broadcast. However, when fertilizer P was banded, available soil P was described by a cubic equation related to rate. Tissue P showed no differences for P sources, increased linearly with increasing P rate, and was also affected by P placement. Although tissue-P concentrations were significantly correlated with yields, their variability accounted for only a small portion of the yield variation.

A residual study conducted the following year showed no advantage of additional P fertilization. This showed sufficient residual P from 1971 was available for plant growth in 1972. Maximum yields were

obtained only after rates equivalent to the Langmuir-defined P-sorption maximum of this soil, 84 kg P/ha, were applied. As in the previous year, no yield response to P sources was obtained and response to P rates was linear. Both soil-P levels and tissue-P contents were higher in refertilized plots than in residual plots. However, since additional fertilization did not result in higher yields, it was again suggested that additional P fertilization was superfluous. Though available soil P and tissue-P content both were linearly and curvilinearly correlated with yield, tissue-P content better estimated variation in corn yield than did extracted soil-P values.

In a continuation of the study of residual P after another year, corn yields were found to be higher on plots fertilized the previous year with P than on those where P was applied 2 years previously. This indicated that observed lack of response to additional fertilization in 1972 did not carry over into 1973. Available soil-P levels, tissue-P concentrations, and yields all linearly increased with P rates. As in the previous studies, tissue-P levels accounted for more yield variation than did available soil-P values. Apparently, tissue-P levels were a somewhat better indicator of corn yields than were soil-P values.

Corn yield response to residual-P levels was noted in both years. In 1972, maximum corn yields were obtained from plots fertilized the previous year with 84 kg P/ha. In 1973, maximum yields were recorded on plots fertilized 2 years previously with 168 kg P/ha. Phosphate-sorption maximum of this soil as defined by the Langmuir equation was 84 kg P/ha. For each year of response to residual P, it appeared that P rates equivalent to Psm had to be applied to Red Bay soil.

With various mixtures of coated and uncoated P fertilizers, maximum

and minimum tissue P levels and yields were produced when mixtures were 20 and 80% SCSP, respectively. A residual study undertaken 2 years later revealed a reversal of these observations and indicated that, in this case, SCSP was more effective as a residual P source for corn than was CSP. In this and previous studies with a constant rate of P fertilization, no high R^2 values were found between yield and soil or various tissue elements. In contrast, studies with wide ranges of P rates, 0-196 kg/ha, did produce somewhat higher R^2 values. Corn yields were projected accurately from available soil P levels in unfertilized plots, but not from those of fertilized plots.

The following conclusions appear to be justified from the results of this investigation.

1. Phosphate sorption in Red Bay fsl was best described by use of the square-root inclusion into the parabolic equation by the method of Gunary (1970), although either Langmuir or Freundlich equations and phosphate potential method also accurately described P sorption at various ranges of applied P.

2. Removal of organic matter and amorphous aluminosilicates had little effect on P retention, while removal of crystalline Fe and Al reduced P retention in this soil by 89%.

3. Phosphate dissolution from CSP granules was retarded by use of S-coating; however, wide variance in P released from SCSP pellets was noted in both laboratory and field studies.

4. Soil moderated acidity of leachate from various P sources by an average of one-half of a pH unit.

5. Soil sorption of P dissolving from fertilizer P granules (1,340 μg P/g soil) was comparable to that described by Langmuir equation

(1,560 μg P/g soil) for rates of applied P up to 5,000 μg/g soil.

6. Corn yield response was alike between individual P sources; however, with CSP and SCSP combinations, different initial and residual responses were obtained.

7. Corn yield response was alike between broadcast and band placements over a range of P rates.

8. Corn yield response, soil-P levels, and tissue-P levels were linearly related to rate of applied P.

9. Maximum corn yield response to levels of residual soil P resulting from applied rates of 84 and 168 kg P/ha was obtained after 1 and 2 years, respectively.

10. Both available soil-P values and P content of corn ear-leaf tissue sampled at late-silking stage were linearly and curvilinearly correlated with yield; highest accounts of yield variation by the above P levels were slightly greater than 50%.

11. Estimation of variation in corn yields by both available soil-P and tissue-P levels was better where wide, rather than narrow, ranges of P rates were employed.

12. Corn yields could be projected accurately from available soil-P levels in unfertilized plots, but not from those of fertilized plots.

APPENDIX

Table 28. Rainfall on field plots in 1971 from time of planting until corn harvest

Time after planting weeks	Rainfall per week cm
1	4.62
2	3.35
3	1.70
4	0.00
5	4.39
6	0.30
7	0.00
8	3.02
9	0.91
10	1.75
11	1.09
12	1.19
13	0.53
14	5.51
15	1.45
16	4.29
17	1.96
18	0.36
19	11.25
20	5.77
21	1.55
22	0.56
23	3.43
24	1.93
25	8.13
26	0.00
27	3.25

Table 29. Corn yields in 1971 from plots fertilized with several rates of CSP and two SCSP fertilizers with broadcast and band placement

Treatment		Replication				Mean
P rate	Placement	1	2	3	4	
kg/ha		Yield, kg/ha				
		Check				
0		3,150	2,040	4,680	4,710	3,640
		2,940	3,320	4,380	5,110	3,940
		CSP (20.1% P)				
28	Broadcast	7,310	6,160	7,730	8,630	7,450
	Band	6,380	6,970	7,310	9,110	7,450
56	Broadcast	5,960	8,070	8,420	9,520	8,000
	Band	7,180	6,330	7,660	7,940	7,310
84	Broadcast	9,320	7,310	8,000	8,900	8,420
	Band	7,870	7,590	9,040	9,180	8,420
112	Broadcast	8,140	7,730	8,900	8,690	8,350
	Band	4,730	7,180	8,000	9,110	7,250
140	Broadcast	8,490	8,630	8,900	9,380	8,830
	Band	7,870	8,140	7,800	8,000	7,940
168	Broadcast	7,800	8,350	9,870	10,140	9,040
	Band	6,970	8,760	8,760	9,450	8,490
196	Broadcast	7,250	6,580	9,520	10,280	8,420
	Band	5,870	6,370	9,520	9,940	7,940
		SCSP (15.5% P)				
28	Broadcast	7,520	8,420	6,590	7,180	7,450
	Band	7,110	7,660	7,800	7,800	7,590
56	Broadcast	6,970	7,730	8,070	8,210	7,730
	Band	7,250	6,670	8,000	10,280	8,070
84	Broadcast	8,070	7,590	7,800	8,970	8,140
	Band	5,960	7,940	9,730	6,830	7,590
112	Broadcast	6,110	9,730	7,660	9,940	8,350
	Band	8,210	8,830	8,070	8,630	8,420
140	Broadcast	7,450	8,490	8,900	8,630	8,350
	Band	9,380	7,180	8,690	8,830	8,560

Table 29. Continued

Treatment		Replication				Mean
P rate	Placement	1	2	3	4	
------ kg/ha ------		---------- Yield, kg/ha ----------				
		SCSP (14.8% P)				
28	Broadcast	4,200	8,000	8,070	7,730	7,040
	Band	7,180	9,040	6,670	7,590	7,590
56	Broadcast	7,310	7,590	6,840	8,000	7,452
	Band	6,680	9,320	8,490	7,800	8,073
84	Broadcast	8,420	9,520	8,210	9,590	8,970
	Band	6,620	7,590	7,800	6,110	7,040
112	Broadcast	6,480	8,070	8,280	8,490	7,870
	Band	6,730	7,870	8,070	7,870	7,660
140	Broadcast	7,250	7,940	9,180	8,830	8,280
	Band	7,590	8,830	7,520	7,940	8,000

Table 30. Phosphorus extracted by 0.03N NH_4F in 0.1N HCl from soil samples taken 3 months after fertilization in 1971 with several rates of CSP and two SCSP fertilizers using broadcast and band placement

Treatment		Replication				Mean
P rate	Placement	1	2	3	4	
kg/ha		P, μg/g soil				
		Check				
0		5.1	3.0	6.9	4.9	5.0
		5.8	6.3	5.6	5.4	5.8
		CSP (20.1% P)				
28	Broadcast	7.6	3.9	10.4	17.6	9.9
	Band	12.3	4.9	15.6	20.4	13.3
56	Broadcast	8.4	4.8	7.4	13.1	8.4
	Band	8.9	4.5	24.0	11.7	12.3
84	Broadcast	14.1	6.4	10.0	6.1	9.2
	Band	7.5	9.5	12.0	7.7	9.2
112	Broadcast	5.3	10.4	11.1	7.0	8.5
	Band	9.0	6.8	6.6	8.1	7.6
140	Broadcast	13.0	11.1	10.2	7.0	10.6
	Band	7.4	6.6	7.0	5.5	6.6
168	Broadcast	7.0	14.6	15.7	18.7	14.0
	Band	7.6	10.9	13.4	14.3	11.6
196	Broadcast	6.9	9.5	14.0	21.1	12.9
	Band	8.9	9.5	12.5	16.4	11.8
		SCSP (15.5% P)				
28	Broadcast	7.8	6.8	5.7	4.9	6.3
	Band	3.7	9.5	9.0	7.7	7.5
56	Broadcast	7.7	7.4	8.8	18.9	10.7
	Band	6.6	7.5	8.2	30.8	13.3
84	Broadcast	5.7	3.2	14.7	6.5	7.5
	Band	5.4	14.2	16.8	5.5	10.5
112	Broadcast	14.6	17.1	17.1	12.2	15.3
	Band	8.4	8.0	9.1	9.0	8.6
140	Broadcast	7.5	4.4	17.5	9.8	10.0
	Band	4.9	8.3	24.1	19.2	14.1

Table 30. Continued

Treatment		Replication				Mean
P rate	Placement	1	2	3	4	
kg/ha		P, µg/g soil				
		SCSP (14.8% P)				
28	Broadcast	5.7	5.0	4.3	4.5	4.9
	Band	5.9	15.1	3.8	5.7	7.6
56	Broadcast	7.0	6.2	6.0	8.2	6.9
	Band	4.6	16.3	5.0	10.6	10.8
84	Broadcast	7.5	13.3	25.7	12.8	14.8
	Band	5.5	6.6	6.5	4.5	5.8
112	Broadcast	5.7	9.0	6.0	3.2	6.0
	Band	4.4	6.5	10.8	6.9	7.2
140	Broadcast	6.0	5.1	12.0	13.9	9.3
	Band	7.0	11.1	10.3	6.5	8.7

Table 31. Phosphorus extracted by 0.03N NH_4F and 0.1N HCl from soil samples taken 6 months after fertilization in 1971 with several rates of CSP and two SCSP fertilizers using broadcast and band placement

Treatment		Replication				Mean
P rate	Placement	1	2	3	4	
kg/ha		P, µg/g soil				
		Check				
0		4.6	3.2	4.4	5.7	4.5
		CSP (20.1% P)				
28	Broadcast	12.1	8.9	9.0	20.2	12.6
	Band	73.5	135.0	105.0	105.0	105.0
56	Broadcast*	36.4	39.6	38.7	31.0	36.4
84	Broadcast	86.0	33.1	51.0	38.4	52.1
	Band	153.0	234.0	125.0	99.0	153.0
112	Broadcast*	70.0	69.5	98.5	41.8	70.0
140	Broadcast	102.0	136.0	196.0	96.5	133.0
	Band	380.0	1030.0	625.0	585.0	655.0
168	Broadcast*	261.0	76.5	46.9	233.0	154.0
196	Broadcast*	174.0	158.0	210.0	154.0	174.0
		SCSP (15.5% P)				
28	Broadcast	8.4	9.7	10.3	11.1	9.9
	Band	8.5	57.5	22.5	29.5	29.5
56	Broadcast*	47.1	14.4	35.0	33.3	32.5
84	Broadcast	29.2	29.5	30.0	39.2	32.0
	Band	137.0	200.0	150.0	218.0	176.0
112	Broadcast*	70.0	20.3	55.5	57.5	50.8
140	Broadcast	135.0	101.0	60.5	80.5	94.3
	Band	156.0	368.0	370.0	303.0	299.0

Table 31. Continued

Treatment		Replication				Mean
P rate	Placement	1	2	3	4	
kg/ha		P, µg/g soil				
		SCSP (14.8% P)				
28	Broadcast	11.9	13.5	25.6	28.3	19.8
	Band	135.0	195.0	178.0	205.0	178.0
56	Broadcast*	40.5	62.5	71.0	76.0	62.5
84	Broadcast	78.0	38.7	42.7	48.5	52.0
	Band	129.0	129.0	109.0	70.0	109.0
112	Broadcast*	71.0	47.9	96.5	49.0	66.1
140	Broadcast	83.5	164.0	58.0	131.0	109.0
	Band	275.0	275.0	377.0	760.0	422.0

* Only broadcast placement was sampled from these plots.

Table 32. Phosphorus in corn plant tissue at 2 months of age from plots fertilized in 1971 with several rates of CSP and two SCSP fertilizers with broadcast and band placement

Treatment		Replication				Mean
P rate	Placement	1	2	3	4	
kg/ha		P, %				
		Check				
0		0.192	0.167	0.214	0.235	0.202
		0.211	0.245	0.243	0.204	0.226
		CSP (20.1% P)				
28	Broadcast	0.214	0.251	0.231	0.308	0.251
	Band	0.287	0.298	0.325	0.235	0.286
56	Broadcast	0.354	0.265	0.223	0.304	0.287
	Band	0.282	0.265	0.187	0.197	0.233
84	Broadcast	0.223	0.260	0.287	0.248	0.255
	Band	0.376	0.287	0.245	0.255	0.291
112	Broadcast	0.270	0.265	0.209	0.192	0.234
	Band	0.345	0.255	0.258	0.265	0.281
140	Broadcast	0.415	0.273	0.265	0.308	0.315
	Band	0.472	0.257	0.287	0.233	0.312
168	Broadcast	0.389	0.338	0.235	0.367	0.332
	Band	0.427	0.235	0.298	0.389	0.337
196	Broadcast	0.405	0.315	0.350	0.287	0.337
	Band	0.382	0.235	0.313	0.235	0.291
		SCSP (15.5% P)				
28	Broadcast	0.264	0.282	0.248	0.211	0.251
	Band	0.298	0.287	0.265	0.303	0.288
56	Broadcast	0.223	0.265	0.338	0.348	0.294
	Band	0.255	0.291	0.245	0.415	0.302
84	Broadcast	0.214	0.245	0.366	0.245	0.268
	Band	0.298	0.265	0.330	0.277	0.293
112	Broadcast	0.270	0.427	0.248	0.252	0.299
	Band	0.320	0.405	0.338	0.389	0.363
140	Broadcast	0.291	0.330	0.345	0.265	0.308
	Band	0.422	0.320	0.350	0.422	0.379

Table 32. Continued

Treatment		Replication				Mean
P rate	Placement	1	2	3	4	
kg/ha		P, %				
		SCSP (14.8% P)				
28	Broadcast	0.211	0.287	0.281	0.235	0.254
	Band	0.199	0.350	0.304	0.270	0.881
56	Broadcast	0.228	0.245	0.299	0.328	0.275
	Band	0.354	0.245	0.245	0.269	0.278
84	Broadcast	0.308	0.333	0.245	0.223	0.277
	Band	0.408	0.298	0.260	0.196	0.291
112	Broadcast	0.313	0.296	0.238	0.315	0.291
	Band	0.333	0.330	0.226	0.281	0.293
140	Broadcast	0.238	0.298	0.345	0.289	0.293
	Band	0.287	0.231	0.313	0.265	0.274

Table 33. Phosphorus in corn ear-leaf tissue at 3 months of age from plots fertilized in 1971 with several rates of CSP and two SCSP fertilizers with broadcast and band placement

Treatment		Replication				Mean
P rate	Placement	1	2	3	4	
kg/ha		P, %				
		Check				
0		0.110	0.129	0.197	0.194	0.158
		0.213	0.151	0.194	0.175	0.183
		CSP (20.1% P)				
28	Broadcast	0.240	0.189	0.219	0.247	0.218
	Band	0.221	0.175	0.223	0.243	0.216
56	Broadcast	0.279	0.228	0.228	0.238	0.243
	Band	0.219	0.202	0.218	0.197	0.209
84	Broadcast	0.255	0.221	0.221	0.240	0.234
	Band	0.228	0.196	0.235	0.196	0.214
112	Broadcast	0.235	0.260	0.257	0.231	0.246
	Band	0.185	0.223	0.219	0.187	0.204
140	Broadcast	0.247	0.243	0.223	0.260	0.243
	Band	0.264	0.206	0.202	0.209	0.202
168	Broadcast	0.243	0.240	0.262	0.255	0.250
	Band	0.260	0.278	0.238	0.231	0.252
196	Broadcast	0.238	0.235	0.253	0.277	0.251
	Band	0.219	0.243	0.257	0.228	0.237
		SCSP (15.5% P)				
28	Broadcast	0.213	0.209	0.228	0.194	0.211
	Band	0.196	0.213	0.218	0.192	0.205
56	Broadcast	0.228	0.209	0.235	0.279	0.238
	Band	0.196	0.189	0.231	0.256	0.218
84	Broadcast	0.218	0.213	0.238	0.228	0.224
	Band	0.209	0.184	0.282	0.175	0.213
112	Broadcast	0.238	0.255	0.221	0.238	0.238
	Band	0.245	0.243	0.231	0.218	0.234
140	Broadcast	0.272	0.253	0.218	0.255	0.250
	Band	0.252	0.218	0.264	0.255	0.247

Table 33. Continued

Treatment		Replication				Mean
P rate	Placement	1	2	3	4	
kg/ha		P, %				
		SCSP (14.8% P)				
28	Broadcast	0.192	0.206	0.228	0.205	0.208
	Band	0.192	0.223	0.213	0.195	0.206
56	Broadcast	0.230	0.202	0.218	0.270	0.230
	Band	0.172	0.218	0.196	0.235	0.205
84	Broadcast	0.253	0.238	0.223	0.230	0.236
	Band	0.218	0.228	0.213	0.177	0.209
112	Broadcast	0.228	0.240	0.230	0.238	0.234
	Band	0.235	0.206	0.228	0.223	0.223
140	Broadcast	0.264	0.223	0.280	0.264	0.258
	Band	0.231	0.238	0.264	0.214	0.237

Table 34. Aluminum in corn plant tissue at 2 months of age from plots fertilized in 1971 with several rates of CSP and two SCSP fertilizers with broadcast and band placement

Treatment		Replication				Mean
P rate	Placement	1	2	3	4	
kg/ha		Al, ppm				
		Check				
0		1,000	1,250	1,200	1,200	1,160
		1,180	1,530	1,300	1,130	1,290
		CSP (20.1% P)				
28	Broadcast	1,180	790	375	825	793
	Band	1,700	800	500	425	856
56	Broadcast	900	850	525	725	750
	Band	600	350	475	525	489
84	Broadcast	950	650	675	475	688
	Band	950	550	375	375	563
112	Broadcast	775	475	325	350	481
	Band	950	350	525	550	594
140	Broadcast	800	550	350	600	575
	Band	975	575	625	825	750
168	Broadcast	600	650	200	250	425
	Band	700	525	275	325	456
196	Broadcast	750	500	450	450	538
	Band	750	400	300	200	413
		SCSP (15.5% P)				
28	Broadcast	875	650	850	1,450	956
	Band	1,680	825	900	1,100	1,120
56	Broadcast	1,330	950	700	650	908
	Band	1,000	650	650	575	719
84	Broadcast	775	1,210	700	600	821
	Band	775	450	400	650	569
112	Broadcast	825	675	950	925	844
	Band	1,030	600	1,080	700	850
140	Broadcast	1,050	700	750	300	700
	Band	825	375	575	525	575

Table 34. Continued

Treatment		Replication				Mean
P rate	Placement	1	2	3	4	
kg/ha		Al, ppm				
		SCSP (14.8% P)				
28	Broadcast	1,250	1,030	675	725	920
	Band	1,500	1,080	1,330	1,250	1,290
56	Broadcast	950	925	775	500	788
	Band	975	525	1,000	350	713
84	Broadcast	925	825	600	475	706
	Band	1,130	500	625	550	701
112	Broadcast	925	625	475	575	650
	Band	1,025	400	400	400	556
140	Broadcast	700	1,130	1,000	425	814
	Band	900	375	475	550	575

Table 35. Aluminum in corn ear-leaf tissue at 3 months of age from plots fertilized in 1971 with several rates of CSP and two SCSP fertilizers with broadcast and band placement

Treatment		Replication				Mean
P rate	Placement	1	2	3	4	
kg/ha		Al, ppm				
		Check				
0		300	200	200	175	219
		100	150	150	250	163
		CSP (20.1% P)				
28	Broadcast	100	200	150	125	144
	Band	125	200	150	100	144
56	Broadcast	138	175	300	225	210
	Band	100	225	200	225	188
84	Broadcast	100	175	125	125	131
	Band	75	200	125	225	156
112	Broadcast	100	175	125	200	150
	Band	100	175	100	200	144
140	Broadcast	125	150	125	175	144
	Band	150	125	125	200	150
168	Broadcast	75	125	125	175	125
	Band	100	125	125	225	144
196	Broadcast	150	150	150	250	175
	Band	138	225	200	225	197
		SCSP (15.5% P)				
28	Broadcast	100	100	175	100	119
	Band	125	50	225	75	119
56	Broadcast	100	75	175	125	119
	Band	125	75	125	125	113
84	Broadcast	100	75	100	100	94
	Band	75	75	125	100	94
112	Broadcast	100	100	100	100	100
	Band	100	150	150	175	144
140	Broadcast	100	125	275	225	181
	Band	75	150	250	225	175

Table 35. Continued

Treatment		Replication				Mean
P rate	Placement	1	2	3	4	
kg/ha		Al, ppm				
		SCSP (14.8% P)				
28	Broadcast	250	125	150	188	178
	Band	100	100	150	125	119
56	Broadcast	50	100	150	100	100
	Band	100	75	250	125	138
84	Broadcast	125	100	75	125	106
	Band	75	150	125	100	113
112	Broadcast	75	125	100	175	119
	Band	75	125	100	175	119
140	Broadcast	50	75	150	150	106
	Band	75	125	75	75	88

Table 36. Iron in corn plant tissue at 2 months of age from plots fertilized in 1971 with several rates of CSP and two SCSP fertilizers with broadcast and band placement

Treatment		Replication				Mean
P rate	Placement	1	2	3	4	
kg/ha		Fe, ppm				
		Check				
0		515	640	630	540	581
		590	700	630	535	614
		CSP (20.1% P)				
28	Broadcast	565	411	219	450	411
	Band	750	375	305	188	405
56	Broadcast	460	415	270	385	383
	Band	330	188	253	280	263
84	Broadcast	390	393	280	255	330
	Band	515	235	225	189	291
112	Brcadcast	353	445	178	235	303
	Band	565	240	290	278	343
140	Broadcast	560	610	245	665	520
	Band	485	215	348	183	308
168	Broadcast	258	375	153	202	247
	Band	370	445	200	215	308
196	Broadcast	415	290	258	305	317
	Band	355	185	180	180	225
		SCSP (15.5% P)				
28	Broadcast	505	385	358	695	486
	Band	735	420	440	580	544
56	Broadcast	640	455	375	358	457
	Band	505	330	280	308	356
84	Broadcast	395	648	315	275	408
	Band	425	303	215	333	319
112	Broadcast	368	383	430	480	415
	Band	503	315	570	405	448
140	Broadcast	453	315	365	180	328
	Band	440	240	343	325	337

Table 36. Continued

Treatment		Replication				Mean
P rate	Placement	1	2	3	4	
kg/ha		Fe, ppm				
		SCSP (14.8% P)				
28	Broadcast	625	470	273	360	432
	Band	788	570	665	675	675
56	Broadcast	505	415	380	295	399
	Band	470	265	455	205	349
84	Broadcast	445	385	285	275	348
	Band	525	325	350	318	380
112	Broadcast	470	330	198	313	328
	Band	468	243	223	245	295
140	Broadcast	373	520	252	229	344
	Band	375	265	218	240	275

Table 37. Iron in corn ear-leaf tissue at 3 months of age from plots fertilized in 1971 with several rates of CSP and two SCSP fertilizers with broadcast and band placement

Treatment		Replication				Mean
P rate	Placement	1	2	3	4	
kg/ha		Fe, ppm				
		Check				
0		178	158	200	165	175
		136	136	163	145	145
		CSP (20.1% P)				
28	Broadcast	265	160	143	138	177
	Band	170	155	168	135	157
56	Broadcast	179	143	210	175	177
	Band	119	190	163	178	163
84	Broadcast	136	178	158	130	151
	Band	116	180	198	158	163
112	Broadcast	121	145	130	158	139
	Band	106	150	135	150	135
140	Broadcast	130	136	124	147	134
	Band	143	110	129	163	136
168	Broadcast	128	128	142	158	139
	Band	114	136	145	221	154
196	Broadcast	155	196	142	165	165
	Band	145	185	160	175	166
		SCSP (15.5% P)				
28	Broadcast	138	150	143	135	142
	Band	146	109	165	119	135
56	Broadcast	130	116	155	175	144
	Band	136	124	142	144	137
84	Broadcast	114	129	130	120	123
	Band	121	163	245	137	167
112	Broadcast	148	115	143	138	136
	Band	155	240	162	155	178
140	Broadcast	114	128	180	219	160
	Band	130	145	220	210	176

Table 37. Continued

Treatment		Replication				Mean
P rate	Placement	1	2	3	4	
kg/ha		Fe, ppm				
		SCSP (14.8% P)				
28	Broadcast	205	168	153	166	173
	Band	243	121	135	150	162
56	Broadcast	185	130	191	198	176
	Band	280	115	175	140	178
84	Broadcast	163	130	115	147	139
	Band	116	138	178	215	162
112	Broadcast	118	126	245	173	166
	Band	145	145	130	250	168
140	Broadcast	116	137	136	148	134
	Band	112	155	130	124	130

Table 38. Calcium in corn plant tissue at 2 months of age from plots fertilized in 1971 with several rates of CSP and two SCSP fertilizers with broadcast and band placement

Treatment		Replication				Mean
P rate	Placement	1	2	3	4	
kg/ha		Ca, %				
		Check				
0		0.308	0.350	0.333	0.350	0.335
		0.293	0.350	0.333	0.318	0.324
		CSP (20.1% P)				
28	Broadcast	0.283	0.341	0.283	0.432	0.334
	Band	0.400	0.425	0.375	0.330	0.378
56	Broadcast	0.393	0.375	0.380	0.458	0.383
	Band	0.358	0.350	0.283	0.383	0.344
84	Broadcast	0.313	0.395	0.483	0.370	0.390
	Band	0.425	0.438	0.488	0.433	0.446
112	Broadcast	0.350	0.355	0.313	0.400	0.355
	Band	0.383	0.300	0.333	0.408	0.356
140	Broadcast	0.438	0.338	0.375	0.420	0.392
	Band	0.400	0.430	0.388	0.383	0.400
168	Broadcast	0.358	0.504	0.343	0.393	0.400
	Band	0.388	0.450	0.395	0.480	0.428
196	Broadcast	0.343	0.450	0.433	0.433	0.415
	Band	0.413	0.380	0.445	0.293	0.383
		SCSP (15.5% P)				
28	Broadcast	0.333	0.325	0.350	0.375	0.346
	Band	0.363	0.438	0.425	0.425	0.413
56	Broadcast	0.325	0.405	0.343	0.325	0.350
	Band	0.325	0.458	0.395	0.400	0.394
84	Broadcast	0.318	0.462	0.388	0.400	0.392
	Band	0.408	0.375	0.318	0.426	0.381
112	Broadcast	0.313	0.383	0.350	0.463	0.377
	Band	0.443	0.400	0.425	0.493	0.440
140	Broadcast	0.325	0.420	0.475	0.388	0.402
	Band	0.333	0.388	0.475	0.486	0.420

Table 38. Continued

Treatment		Replication				Mean
P rate	Placement	1	2	3	4	
kg/ha		Ca, %				
		SCSP (14.8% P)				
28	Broadcast	0.300	0.343	0.263	0.333	0.310
	Band	0.333	0.458	0.393	0.475	0.414
56	Broadcast	0.300	0.313	0.375	0.375	0.341
	Band	0.333	0.275	0.325	0.358	0.323
84	Broadcast	0.413	0.363	0.363	0.393	0.383
	Band	0.380	0.420	0.370	0.388	0.390
112	Broadcast	0.308	0.318	0.325	0.425	0.344
	Band	0.318	0.438	0.375	0.450	0.395
140	Broadcast	0.343	0.445	0.433	0.318	0.385
	Band	0.333	0.300	0.388	0.405	0.357

Table 39. Calcium in corn ear-leaf tissue at 3 months of age from plots fertilized in 1971 with several rates of CSP and two SCSP fertilizers with broadcast and band placement

Treatment		Replication				Mean
P rate	Placement	1	2	3	4	
kg/ha		Ca, %				
		Check				
0		0.308	0.243	0.308	0.318	0.294
		0.300	0.208	0.308	0.258	0.269
		CSP (20.1% P)				
28	Broadcast	0.318	0.333	0.313	0.418	0.345
	Band	0.225	0.343	0.383	0.408	0.340
56	Broadcast	0.372	0.400	0.418	0.443	0.408
	Band	0.300	0.383	0.383	0.408	0.368
84	Broadcast	0.358	0.375	0.408	0.458	0.400
	Band	0.318	0.350	0.408	0.425	0.375
112	Broadcast	0.325	0.443	0.408	0.466	0.410
	Band	0.293	0.418	0.350	0.350	0.353
140	Broadcast	0.300	0.432	0.333	0.408	0.363
	Band	0.308	0.350	0.368	0.450	0.369
168	Broadcast	0.333	0.393	0.433	0.500	0.415
	Band	0.333	0.408	0.343	0.508	0.398
196	Broadcast	0.408	0.350	0.475	0.483	0.429
	Band	0.309	0.358	0.418	0.400	0.371
		SCSP (15.5% P)				
28	Broadcast	0.300	0.333	0.383	0.368	0.346
	Band	0.308	0.333	0.368	0.293	0.326
56	Broadcast	0.293	0.350	0.368	0.432	0.361
	Band	0.350	0.258	0.358	0.350	0.329
84	Broadcast	0.358	0.343	0.425	0.308	0.359
	Band	0.293	0.343	0.358	0.418	0.353
112	Broadcast	0.243	0.358	0.383	0.408	0.348
	Band	0.308	0.408	0.408	0.426	0.387
140	Broadcast	0.300	0.408	0.400	0.458	0.392
	Band	0.358	0.325	0.468	0.425	0.394

Table 39. Continued

Treatment		Replication				Mean
P rate	Placement	1	2	3	4	
kg/ha		Ca, %				
		SCSP (14.8% P)				
28	Broadcast	0.218	0.275	0.325	0.304	0.281
	Band	0.300	0.383	0.318	0.343	0.336
56	Broadcast	0.333	0.325	0.358	0.408	0.356
	Band	0.225	0.383	0.408	0.325	0.335
84	Broadcast	0.318	0.318	0.433	0.408	0.370
	Band	0.300	0.383	0.368	0.318	0.342
112	Broadcast	0.308	0.358	0.393	0.393	0.363
	Band	0.333	0.375	0.393	0.425	0.382
140	Broadcast	0.383	0.343	0.418	0.425	0.392
	Band	0.275	0.368	0.393	0.358	0.349

Table 40. Potassium in corn plant tissue at 2 months of age from plots fertilized in 1971 with several rates of CSP and two SCSP fertilizers with broadcast and band placement

Treatment		Replication				Mean
P rate	Placement	1	2	3	4	
kg/ha		K, %				
		Check				
0		4.03	4.45	4.25	4.35	4.28
		4.45	5.15	4.85	3.98	4.61
		CSP (20.1% P)				
28	Broadcast	4.73	5.50	4.58	7.18	5.50
	Band	5.35	5.45	5.25	4.15	5.05
56	Broadcast	6.33	5.55	4.60	6.70	5.80
	Band	5.30	4.55	4.45	5.25	4.89
84	Broadcast	5.00	5.10	5.88	4.23	5.05
	Band	5.75	5.30	5.55	3.53	5.03
112	Broadcast	4.88	5.00	3.90	3.93	4.43
	Band	6.33	5.35	5.25	4.50	5.36
140	Broadcast	5.80	4.70	4.65	4.65	4.95
	Band	7.20	4.35	4.75	3.80	5.03
168	Broadcast	5.88	4.80	4.40	5.30	5.10
	Band	5.30	3.75	4.70	5.13	4.72
196	Broadcast	6.63	4.80	5.40	5.50	5.58
	Band	5.25	4.65	5.30	3.10	4.58
		SCSP (15.5% P)				
28	Broadcast	4.63	4.90	4.70	3.98	4.55
	Band	5.50	5.45	5.55	5.95	5.64
56	Broadcast	3.85	4.80	6.05	5.75	5.11
	Band	4.70	5.70	4.50	6.45	5.35
84	Broadcast	4.33	6.50	6.05	4.15	5.26
	Band	4.58	4.05	5.00	5.40	4.76
112	Broadcast	4.35	6.35	4.30	5.20	5.05
	Band	6.75	5.80	6.05	5.25	5.96
140	Broadcast	4.30	5.70	5.95	4.50	5.10
	Band	5.88	4.70	5.80	6.58	5.74

Table 40. Continued

Treatment		Replication				Mean
P rate	Placement	1	2	3	4	
kg/ha		K, %				
		SCSP (14.8% P)				
28	Broadcast	3.93	5.25	4.35	4.38	4.48
	Band	3.60	6.50	6.13	5.55	5.45
56	Broadcast	4.70	3.80	5.08	5.35	4.73
	Band	5.60	4.08	4.35	5.13	4.79
84	Broadcast	5.30	4.50	3.90	3.45	4.29
	Band	5.20	5.45	4.50	3.65	4.70
112	Broadcast	4.73	5.08	3.95	5.00	4.69
	Band	5.00	5.35	3.95	6.20	5.13
140	Broadcast	3.80	5.25	6.25	5.08	5.10
	Band	4.70	4.53	5.30	4.70	4.81

Table 41. Potassium in corn ear-leaf tissue at 3 months of age from plots fertilized in 1971 with several rates of CSP and two SCSP fertilizers with broadcast and band placement

Treatment		Replication				Mean
P rate	Placement	1	2	3	4	
kg/ha		K, %				
		Check				
0		2.78	2.50	2.85	2.63	2.69
		2.90	2.58	2.90	2.70	2.77
		CSP (20.1% P)				
28	Broadcast	2.68	2.65	2.68	2.93	2.74
	Band	2.53	2.53	2.83	2.55	2.61
56	Broadcast	2.64	2.38	2.63	2.43	2.52
	Band	2.75	2.43	2.55	2.45	2.55
84	Broadcast	2.55	2.33	2.38	2.30	2.39
	Band	2.63	2.53	2.38	2.23	2.44
112	Broadcast	2.28	2.30	2.38	2.18	2.29
	Band	2.43	2.55	2.33	1.85	2.30
140	Broadcast	2.68	2.03	2.30	2.18	2.30
	Band	2.85	2.43	2.30	2.30	2.45
168	Broadcast	2.63	2.78	2.60	2.25	2.57
	Band	2.68	2.20	2.45	2.28	2.40
196	Broadcast	2.05	2.75	2.75	2.38	2.48
	Band	2.40	2.30	2.68	2.33	2.43
		SCSP (15.5% P)				
28	Broadcast	2.68	2.63	2.75	2.53	2.65
	Band	2.28	2.63	2.83	2.55	2.57
56	Broadcast	2.63	2.40	2.60	2.80	2.61
	Band	2.45	2.18	2.53	2.79	2.49
84	Broadcast	2.53	2.33	2.80	2.63	2.57
	Band	2.43	2.30	2.60	2.50	2.41
112	Broadcast	2.80	2.63	2.40	2.33	2.54
	Band	2.98	2.78	2.38	2.13	2.57
140	Broadcast	2.55	2.43	2.58	2.60	2.54
	Band	2.98	2.60	2.93	2.43	2.74

Table 41. Continued

Treatment		Replication				Mean
P rate	Placement	1	2	3	4	
kg/ha		K, %				
		SCSP (14.8% P)				
28	Broadcast	2.90	2.53	2.75	2.53	2.68
	Band	2.68	2.60	2.38	2.50	2.54
56	Broadcast	2.68	2.38	2.55	2.55	2.54
	Band	2.55	2.75	2.60	2.65	2.64
84	Broadcast	2.83	2.53	2.75	2.13	2.56
	Band	2.50	2.40	2.55	2.03	2.37
112	Broadcast	2.68	2.53	2.50	2.38	2.52
	Band	2.85	2.53	2.40	2.45	2.56
140	Broadcast	2.68	2.38	2.53	2.40	2.50
	Band	2.60	2.60	2.60	2.28	2.52

Table 42. Magnesium in corn plant tissue at 2 months of age from plots fertilized in 1971 with several rates od CSP and two SCSP fertilizers with broadcast and band placement

Treatment		Replication				Mean
P rate	Placement	1	2	3	4	
kg/ha		Mg, %				
		Check				
0		0.203	0.260	0.250	0.238	0.238
		0.203	0.265	0.248	0.215	0.239
		CSP (20.1% P)				
28	Broadcast	0.133	0.234	0.224	0.344	0.234
	Band	0.193	0.250	0.258	0.243	0.236
56	Broadcast	0.230	0.255	0.205	0.310	0.250
	Band	0.175	0.253	0.218	0.258	0.226
84	Broadcast	0.158	0.235	0.330	0.235	0.240
	Band	0.223	0.248	0.305	0.324	0.275
112	Broadcast	0.138	0.283	0.201	0.258	0.220
	Band	0.176	0.270	0.253	0.330	0.257
140	Broadcast	0.203	0.238	0.275	0.263	0.245
	Band	0.206	0.265	0.285	0.239	0.249
168	Broadcast	0.164	0.366	0.218	0.299	0.260
	Band	0.168	0.338	0.290	0.356	0.288
196	Broadcast	0.178	0.313	0.293	0.298	0.270
	Band	0.233	0.283	0.335	0.208	0.257
		SCSP (15.5% P)				
28	Broadcast	0.141	0.244	0.218	0.228	0.208
	Band	0.165	0.280	0.235	0.288	0.242
56	Broadcast	0.140	0.265	0.235	0.280	0.230
	Band	0.158	0.323	0.230	0.273	0.246
84	Broadcast	0.123	0.350	0.313	0.223	0.252
	Band	0.151	0.243	0.293	0.313	0.250
112	Broadcast	0.188	0.293	0.220	0.325	0.257
	Band	0.285	0.258	0.269	0.330	0.285
140	Broadcast	0.155	0.285	0.295	0.228	0.241
	Band	0.191	0.263	0.308	0.350	0.278

Table 42. Continued

Treatment		Replication				Mean
P rate	Placement	1	2	3	4	
kg/ha		Mg, %				
		SCSP (14.8% P)				
28	Broadcast	0.130	0.265	0.243	0.221	0.215
	Band	0.155	0.350	0.254	0.268	0.257
56	Broadcast	0.140	0.153	0.248	0.234	0.194
	Band	0.169	0.180	0.213	0.250	0.203
84	Broadcast	0.200	0.255	0.198	0.229	0.221
	Band	0.185	0.303	0.258	0.195	0.235
112	Broadcast	0.141	0.253	0.235	0.280	0.227
	Band	0.143	0.275	0.263	0.280	0.240
140	Broadcast	0.163	0.278	0.299	0.238	0.245
	Band	0.188	0.220	0.255	0.283	0.237

Table 43. Magnesium in corn ear-leaf tissue at 3 months of age from plots fertilized in 1971 with several rates of CSP and two SCSP fertilizers with broadcast and band placement

Treatment		Replication				Mean
P rate	Placement	1	2	3	4	
kg/ha		Mg, %				
		Check				
0		0.151	0.168	0.210	0.186	0.179
		0.159	0.155	0.211	0.156	0.170
		CSP (20.1% P)				
28	Broadcast	0.109	0.164	0.180	0.220	0.168
	Band	0.130	0.176	0.219	0.230	0.189
56	Broadcast	0.128	0.201	0.203	0.198	0.183
	Band	0.110	0.176	0.203	0.200	0.172
84	Broadcast	0.129	0.179	0.234	0.239	0.195
	Band	0.120	0.179	0.184	0.225	0.177
112	Broadcast	0.115	0.231	0.213	0.210	0.192
	Band	0.100	0.203	0.190	0.169	0.166
140	Broadcast	0.091	0.251	0.176	0.203	0.180
	Band	0.094	0.188	0.230	0.125	0.192
168	Broadcast	0.114	0.215	0.188	0.240	0.189
	Band	0.119	0.210	0.186	0.215	0.172
196	Broadcast	0.216	0.180	0.208	0.204	0.202
	Band	0.120	0.195	0.219	0.191	0.181
		SCSP (15.5% P)				
28	Broadcast	0.113	0.200	0.196	0.195	0.176
	Band	0.115	0.214	0.195	0.165	0.172
56	Broadcast	0.120	0.158	0.199	0.213	0.173
	Band	0.128	0.138	0.195	0.175	0.159
84	Broadcast	0.120	0.193	0.231	0.196	0.185
	Band	0.153	0.130	0.180	0.190	0.163
112	Broadcast	0.110	0.183	0.180	0.206	0.190
	Band	0.115	0.234	0.168	0.231	0.187
140	Broadcast	0.113	0.204	0.193	0.204	0.179
	Band	0.125	0.170	0.219	0.195	0.177

Table 43. Continued

Treatment		Replication				Mean
P rate	Placement	1	2	3	4	
kg/ha		Mg, %				
		SCSP (14.8% P)				
28	Broadcast	0.098	0.153	0.184	0.163	0.150
	Band	0.111	0.199	0.184	0.165	0.165
56	Broadcast	0.108	0.155	0.211	0.199	0.168
	Band	0.100	0.155	0.201	0.165	0.155
84	Broadcast	0.124	0.196	0.198	0.198	0.179
	Band	0.123	0.204	0.198	0.146	0.168
112	Broadcast	0.105	0.189	0.215	0.196	0.177
	Band	0.120	0.191	0.191	0.213	0.179
140	Broadcast	0.141	0.186	0.235	0.191	0.188
	Band	0.111	0.193	0.216	0.153	0.168

Table 44. Manganese in corn plant tissue at 2 months of age from plots fertilized in 1971 with several rates of CSP and two SCSP fertilizers with broadcast and band placement

Treatment		Replication				Mean
P rate	Placement	1	2	3	4	
kg/ha		Mn, ppm				
		Check				
0		360	330	240	368	325
		350	278	235	460	331
		CSP (20.1% P)				
28	Broadcast	375	246	204	160	246
	Band	470	350	280	140	310
56	Broadcast	455	198	220	204	269
	Band	420	140	227	192	245
84	Broadcast	445	218	281	440	346
	Band	415	203	160	380	290
112	Broadcast	493	145	185	255	270
	Band	470	138	204	364	294
140	Broadcast	510	320	150	190	293
	Band	550	265	205	186	302
168	Broadcast	465	275	115	209	266
	Band	438	235	155	255	271
196	Broadcast	405	235	130	163	233
	Band	373	125	115	143	189
		SCSP (15.5% P)				
28	Broadcast	445	265	348	345	351
	Band	525	278	320	310	358
56	Broadcast	595	280	365	125	341
	Band	430	288	303	113	284
84	Broadcast	390	440	130	350	328
	Band	520	330	85	345	320
112	Broadcast	378	338	305	338	340
	Band	469	413	345	350	394
140	Broadcast	315	230	230	215	248
	Band	375	205	213	237	258

Table 44. Continued

Treatment		Replication				Mean
P rate	Placement	1	2	3	4	
kg/ha		Mn, ppm				
		SCSP (14.8% P)				
28	Broadcast	548	300	120	350	330
	Band	565	230	291	325	353
56	Broadcast	470	414	253	197	333
	Band	520	181	205	135	260
84	Broadcast	383	175	268	425	312
	Band	655	203	295	320	368
112	Broadcast	425	210	255	278	292
	Band	360	223	215	218	254
140	Broadcast	525	245	224	165	290
	Band	405	160	240	218	256

Table 45. Manganese in corn ear-leaf tissue at 3 months of age from plots fertilized in 1971 with several rates of CSP and two SCSP fertilizers with broadcast and band placement

Treatment		Replication				Mean
P rate	Placement	1	2	3	4	
kg/ha		Mn, ppm				
		Check				
0		500	166	240	230	284
		470	143	285	248	287
		CSP (20.1% P)				
28	Broadcast	475	240	212	103	258
	Band	345	179	184	135	211
56	Broadcast	500	176	197	207	270
	Band	495	200	248	179	281
84	Broadcast	425	200	194	298	280
	Band	455	190	156	275	269
112	Broadcast	505	154	154	214	257
	Band	500	208	166	286	165
140	Broadcast	595	285	179	120	295
	Band	540	265	202	202	302
168	Broadcast	455	176	184	214	257
	Band	535	198	210	230	293
196	Broadcast	374	148	193	166	220
	Band	344	128	120	133	191
		SCSP (15.5% P)				
28	Broadcast	490	168	290	305	313
	Band	490	154	235	225	276
56	Broadcast	510	245	209	192	289
	Band	475	253	187	125	260
84	Broadcast	560	291	125	250	307
	Band	485	232	110	265	273
112	Broadcast	375	197	240	204	254
	Band	423	214	281	229	289
140	Broadcast	465	202	169	264	275
	Band	470	171	171	164	244

Table 45. Continued

Treatment		Replication				Mean
P rate	Placement	1	2	3	4	
kg/ha		Mn, ppm				
		SCSP (14.8% P)				
28	Broadcast	500	243	148	286	294
	Band	595	216	169	285	316
56	Broadcast	625	302	305	174	351
	Band	425	145	212	139	230
84	Broadcast	403	200	245	475	331
	Band	535	237	275	395	361
112	Broadcast	500	203	248	240	298
	Band	550	198	215	207	293
140	Broadcast	645	209	161	275	323
	Band	460	181	217	240	275

Table 46. Analyses of variance of corn responses, soil and tissue P data of P rate, source, and placement study, 1971

Source	df	Mean squares		
		Stalk and ear responses		
		Stalk no.	Ear no.	Ears/stalk
Blocks	3	1.1296	1.5069	0.0142
Rate (R)				
Linear	1	4.8167	101.4000*	5.5351**
Quadratic	1	38.6786	14.5833	0.5660
Cubic	1	11.7042	3.0375	0.2635
Quartic	1	1.0006	10.5292	0.5385
Source	2	14.4083	32.0250	0.3732
Source x Rate	8	23.7312	14.4937	0.5126
Remainder	3	45.5365	259.9200**	7.4988**
Error (a)	51	18.3631	15.2265	0.4980
Placement (P)	1	0.0278	1.5625	0.1747
P x Rate				
P x Linear	1	2.4000	1.3500	0.0182
P x Quadratic	1	6.8571	0.7619	0.2352
P x Cubic	1	1.2042	1.5042	0.0017
P x Quartic	1	1.2054	1.9339	0.0176
P x Source	2	0.9250	9.5083	0.6536
P x Source x R	8	20.8729	14.4603	1.2449
P x Remainder	3	1.6948	2.8000	1.1010
Error (b)	54	15.7111	21.3896	0.6853

Table 46. Continued

Source	df	Mean squares		
		Yield responses		
		Ave. ear wt.	Kernel wt.	Yield
Blocks	3	12,184.82**	1.0973	15,491,726**
Rate (R)				
Linear	1	1,684.39	0.3098	9,687,898*
Quadratic	1	803.20	4.9461	304,930
Cubic	1	76.09	2.7136	507,262
Quartic	1	15.94	2.6323	556,710
Source	2	106.07	2.6473	551,932
Source x Rate	8	138.90	2.6462	381,611
Remainder	3	7,676.04**	12.1629**	12,801,693**
Error (a)	51	587.84	1.7807	818,283
Placement (P)	1	2,397.27	0.2123	2,107,937
P x Rate				
P x Linear	1	1,047.03	7.1862	1,738,151
P x Quadratic	1	455.96	0.1123	1,273,350
P x Cubic	1	39.66	0.8018	76,860
P x Quartic	1	767.91	0.0102	1,070,600
P x Source	2	490.12	4.6410	807,594
P x Source x R	8	705.67	2.0875	901,891
P x Remainder	3	96.58	1.3691	499,558
Error (b)	54	570.57	2.9255	937,007

Table 46. Continued

Source	df	Mean squares		
		Soil and tissue P responses		
		Soil P June	Tissue P at pre-silking+	Tissue P at late silking+
Blocks	3	87.5214*	0.3110	0.8157
Rates (R)				
Linear	1	7.3150	2.6544*	11.0840**
Quadratic	1	4.9543	0.2080	0.2027
Cubic	1	45.4575	0.0473	0,8932
Quartic	1	0.0330	0.0311	0.3268
Source	2	55.1451	0.9990	0.1132
Source x Rate	8	35.5379	0.2808	0.3916
Remainder	3			
Error (a)	51	30.2580	0.4206	0.6879
Placement (P)	1	1.1603	1.1466*	8,8580**
P x Rate		35.9204*	0.2523	0.3476
P x Linear	1			
P x Quadratic	1			
P x Cubic	1			
P x Quartic	1			
P x Source	2	6.2275	0.3536	0.7140
P x Source x R	8	35.2962	0.1432	0.1578
P x Remainder	3			
Error (b)	54	13.0601	0.1850	0.2707

+ Mean squares must be multiplied by 10^{-2}.
+ Mean squares must be multiplied by 10^{-3}.
* Significant at the 5% level.
** Significant at the 1% level.

Table 47. Correlation coefficients from study of P rate, source, and placement, 1971

Nutrient	Yield		Tissue P			
			Pre-silking stage		Late-silking stage	
	Linear r	Multiple r	Linear r	Multiple r	Linear r	Multiple r
Soil sampled in June 1971						
P	0.1659	0.1706				
Soil sampled in September 1971						
P	-0.075	-0.0323				
Tissue at pre-silking stage						
P	0.1433	0.1948		0.4120**		0.4123
Al	-0.1686*		-0.0614	-0.3264**	0.1360	0.3672
Fe	-0.1609		-0.0247	-0.3271**	0.1277	0.3371
Ca	0.0339		0.3679**	0.1253	0.4008+	0.1311
K	0.0185		0.7020**	0.2471	0.7075	0.2500
Mg	0.0161		0.2165**	0.1137	0.3234+	0.1260
Mn	-0.0902		0.0927	-0.2354**	0.2947+	0.2400
Zn	-0.1380		0.1847*	-0.0805	0.1848	0.1106
Cu	-0.0627		0.1312	-0.0327	0.1848	0.0883
Tissue at late-silking stage						
P	0.2714**	0.2971	0.4120**		0.4123	
Al	-0.0965			-0.1631*		0.2800+
Fe	-0.0956			-0.0405		0.1231
Ca	0.1643			0.3875**		0.3936
K	-0.0280			0.1114		0.1520
Mg	-0.0547			0.1469		0.1573
Mn	-0.0244			-0.0702		0.0718
Si	-0.0209			-0.2201**		0.2327

+ Significant increase over that of linear r value due to inclusion of quadratic term in equation.

* Significant at the 5% level.

** Significant at the 1% level.

Table 48. Corn yields from plots fertilized in 1971 with various combinations of SCSP and CSP or OSP

Treatment		Replication				Mean
84 kg P/ha		1	2	3	4	
SCSP	Additive					
------- % -------		---------- Yield, kg/ha ----------				
		CSP additive				
0	100	7,450	7,870	7,040	9,870	8,070
20	80	7,180	8,280	8,140	9,730	8,350
40	60	7,450	7,250	8,070	9,320	8,000
60	40	7,730	7,180	9,250	8,490	8,140
80	20	6,350	7,940	8,350	8,630	7,800
100	0	6,830	7,940	8,970	10,280	8,490
		OSP additive				
0	100	7,380	8,000	8,210	9,380	8,280
20	80	7,520	7,590	10,350	9,380	8,690
40	60	8,490	7,800	9,040	10,000	8,830
60	40	6,490	7,040	9,800	8,690	8,000
80	20	7,520	6,900	8,280	8,420	7,800
100	0	7,380	10,140	7,450	9,180	8,560

Table 49. Phosphorus extracted by 0.03N NH_4F and 0.1N HCl from soil samples taken 3 months after fertilization in 1971 with various combinations of SCSP and CSP or OSP

Treatment		Replication				Mean
84 kg P/ha		1	2	3	4	
SCSP	Additive					
%		P, µg/g soil				
		CSP additive				
0	100	5.3	8.0	49.5	59.0	30.5
20	80	5.3	19.7	29.0	29.6	20.9
40	60	11.6	18.1	12.5	35.5	19.4
60	40	13.4	12.1	14.6	13.4	13.4
80	20	12.6	15.7	30.2	19.5	19.5
100	0	15.0	27.4	33.7	33.4	27.4
		OSP additive				
0	100	15.5	30.2	32.0	40.5	29.6
20	80	14.8	9.0	18.9	23.5	16.6
40	60	17.0	7.5	44.5	27.0	24.0
60	40	15.0	7.0	30.0	30.0	20.5
80	20	8.8	5.3	10.5	25.0	12.4
100	0	10.6	10.2	10.1	25.5	14.1

Table 50. Phosphorus extracted by 0.03N NH_4F and 0.01N HCl from soil samples taken 6 months after fertilization in 1971 with various combinations of SCSP and CSP or OSP

Treatment		Replication				Mean
84 kg P/ha		1	2	3	4	
SCSP	Additive					
------- % ------		---------- P, µg/g soil ----------				
		CSP additive				
0	100	19.8	15.2	31.0	34.6	25.2
20	80	51.5	16.1	38.0	21.0	31.7
40	60	31.3	36.4	32.0	28.2	32.0
60	40	42.3	42.0	25.5	41.5	37.8
80	20	45.8	45.7	54.5	37.3	45.8
100	0	44.0	47.0	27.3	22.8	43.5
		OSP additive				
0	100	63.5	68.5	66.8	68.5	66.8
20	80	59.0	54.5	39.2	50.9	50.9
40	60	39.7	42.8	68.5	39.7	47.7
60	40	44.8	40.1	31.0	31.5	36.9
80	20	48.2	47.3	34.0	53.5	45.8
100	0	28.8	33.0	36.4	31.0	32.3

Table 51. Phosphorus in corn plant tissue at 2 months of age from plots fertilized in 1971 with various combinations of SCSP and CSP or OSP

Treatment		Replication				Mean
84 kg P/ha		1	2	3	4	
SCSP	Additive					
------- % ------		---------- P, % ----------				
		CSP additive				
0	100	0.282	0.265	0.245	0.230	0.255
20	80	0.265	0.213	0.223	0.206	0.227
40	60	0.225	0.214	0.274	0.219	0.233
60	40	0.298	0.264	0.247	0.281	0.273
80	20	0.180	0.333	0.287	0.252	0.263
100	0	0.231	0.248	0.308	0.238	0.256
		OSP additive				
0	100	0.318	0.255	0.198	0.183	0.239
20	80	0.228	0.211	0.253	0.264	0.239
40	60	0.223	0.245	0.228	0.245	0.236
60	40	0.275	0.347	0.245	0.219	0.272
80	20	0.219	0.298	0.308	0.231	0.264
100	0	0.255	0.393	0.279	0.288	0.304

Table 52. Phosphorus in corn ear-leaf tissue at 3 months of age from plots fertilized in 1971 with various combinations of SCSP and SCP or OSP

Treatment		Replication				Mean
84 kg P/ha		1	2	3	4	
SCSP	Additive					
%		P, %				
		CSP additive				
0	100	0.213	0.213	0.202	0.228	0.214
20	80	0.230	0.223	0.194	0.228	0.219
40	60	0.245	0.213	0.209	0.230	0.224
60	40	0.238	0.235	0.231	0.221	0.231
80	20	0.219	0.218	0.218	0.240	0.224
100	0	0.223	0.225	0.218	0.228	0.223
		OSP additive				
0	100	0.231	0.192	0.223	0.226	0.218
20	80	0.253	0.231	0.230	0.230	0.236
40	60	0.223	0.202	0.206	0.221	0.213
60	40	0.253	0.213	0.248	0.201	0.229
80	20	0.223	0.191	0.196	0.214	0.206
100	0	0.196	0.218	0.230	0.231	0.219

Table 53. Aluminum in corn plant tissue at 2 months of age from plots fertilized in 1971 with various combinations of SCSP and CSP or OSP

Treatment		Replication				Mean
84 kg P/ha		1	2	3	4	
SCSP	Additive					
%		Al, ppm				
		CSP additive				
0	100	800	375	625	350	538
20	80	775	625	625	275	575
40	60	750	800	625	475	663
60	40	675	450	400	500	506
80	20	400	750	650	600	600
100	0	1,050	825	675	325	719
		OSP additive				
0	100	800	1,050	425	250	620
20	80	625	675	375	450	531
40	60	950	625	475	300	588
60	40	1,000	875	425	575	719
80	20	750	525	850	400	631
100	0	725	700	425	650	625

Table 54. Aluminum in corn ear-leaf tissue at 3 months of age from plots fertilized in 1971 with various combinations of SCSP and CSP or OSP

Treatment		Replication				Mean
84 kg P/ha		1	2	3	4	
SCSP	Additive					
------- % ------		---------- Al, ppm ----------				
		CSP additive				
0	100	100	150	100	200	138
20	80	125	150	175	175	156
40	60	75	75	75	125	88
60	40	75	100	125	113	103
80	20	100	125	100	125	113
100	0	75	125	125	100	106
		OSP additive				
0	100	100	75	100	100	94
20	80	75	75	125	150	106
40	60	150	100	125	100	119
60	40	50	175	125	150	125
80	20	50	75	100	75	75
100	0	100	125	175	75	119

Table 55. Iron in corn plant tissue at 2 months of age from plots fertilized in 1971 with various combinations of SCSP and CSP or OSP

Treatment 84 kg P/ha		Replication				Mean
SCSP	Additive	1	2	3	4	
------ % -------		---------- Fe, ppm ----------				
		CSP additive				
0	100	420	250	360	220	313
20	80	323	375	300	205	301
40	60	395	390	325	205	329
60	40	345	300	237	225	277
80	20	245	355	285	250	284
100	0	525	360	348	165	350
		OSP additive				
0	100	495	287	220	145	287
20	80	350	365	235	253	301
40	60	455	303	265	235	315
60	40	498	310	245	268	328
80	20	333	305	245	229	278
100	0	385	388	248	340	340

Table 56. Iron in corn ear-leaf tissue at 3 months of age from plots fertilized in 1971 with various combinations of SCSP and CSP or OSP

Treatment		Replication				Mean
84 kg P/ha		1	2	3	4	
SCSP	Additive					
------ % -------		---------- Fe, ppm ----------				
		CSP additive				
0	100	105	141	117	146	127
20	80	125	115	153	158	138
40	60	93	112	136	138	120
60	40	121	109	138	125	123
80	20	135	140	158	150	146
100	0	116	125	120	148	127
		OSP additive				
0	100	115	142	135	158	138
20	80	114	109	132	135	123
40	60	136	128	126	116	127
60	40	158	158	158	163	159
80	20	111	130	123	145	127
100	0	130	175	158	130	148

Table 57. Calcium in corn plant tissue at 2 months of age from plots fortilized in 1971 with various combinations of SCSP and CSP or OSP

Treatment		Replication				Mean
84 kg P/ha		1	2	3	4	
SCSP	Additive					
------ % -------		---------- Ca, % ----------				
		CSP additive				
0	100	0.358	0.343	0.418	0.400	0.380
20	80	0.475	0.325	0.500	0.393	0.423
40	60	0.300	0.425	0.475	0.395	0.399
60	40	0.318	0.350	0.343	0.395	0.352
80	20	0.300	0.458	0.425	0.380	0.391
100	0	0.283	0.395	0.414	0.355	0.362
		OSP additive				
0	100	0.433	0.358	0.375	0.375	0.385
20	80	0.258	0.325	0.462	0.433	0.370
40	60	0.325	0.380	0.363	0.433	0.375
60	40	0.438	0.468	0.393	0.400	0.425
80	20	0.298	0.408	0.396	0.408	0.378
100	0	0.293	0.438	0.308	0.346	0.346

Table 58. Calcium in corn ear-leaf tissue at 3 months of age from plots fertilized in 1971 with various combinations of SCSP and CSP or OSP

Treatment 84 kg P/ha		Replication				Mean
SCSP	Additive	1	2	3	4	
------ % -------		---------- Ca, % ----------				
		CSP additive				
0	100	0.300	0.383	0.375	0.432	0.372
20	80	0.325	0.358	0.483	0.463	0.407
40	60	0.368	0.358	0.443	0.475	0.411
60	40	0.333	0.350	0.408	0.404	0.374
80	20	0.318	0.363	0.475	0.408	0.391
100	0	0.308	0.350	0.393	0.408	0.365
		OSP additive				
0	100	0.358	0.350	0.400	0.468	0.394
20	80	0.333	0.333	0.425	0.408	0.375
40	60	0.343	0.450	0.450	0.408	0.413
60	40	0.325	0.368	0.375	0.408	0.369
80	20	0.325	0.393	0.376	0.333	0.357
100	0	0.333	0.375	0.400	0.343	0.363

Table 59. Potassium in corn plant tissue at 2 months of age from plots fertilized in 1971 with various combinations of SCSP and CSP or OSP

Treatment		Replication				Mean
84 kg P/ha		1	2	3	4	
SCSP	Additive					
------ % -------		---------- K, % ----------				
		CSP additive				
0	100	5.35	4.10	4.10	3.30	4.21
20	80	3.85	3.65	3.90	3.05	3.61
40	60	3.93	3.90	3.60	3.90	3.83
60	40	5.25	4.83	4.58	3.30	4.49
80	20	3.10	4.65	4.45	3.85	4.00
100	0	4.43	4.00	4.15	3.95	4.13
		OSP additive				
0	100	6.13	4.90	3.40	3.25	4.42
20	80	3.43	3.88	4.20	4.33	3.98
40	60	4.35	4.35	3.55	4.45	4.18
60	40	5.15	4.65	4.70	3.25	4.44
80	20	3.85	4.33	5.00	3.93	4.28
100	0	4.25	4.80	4.25	4.43	4.43

Table 60. Potassium in corn ear-leaf tissue at 3 months of age from plots fertilized in 1971 with various combinations of SCSP and CSP or OSP

Treatment		Replication				Mean
84 kg P/ha		1	2	3	4	
SCSP	Additive					
------ % -------		---------- K, % ----------				
		CSP additive				
0	100	2.28	2.30	2.25	2.18	2.25
20	80	2.50	2.30	1.90	2.15	2.21
40	60	2.25	2.15	1.93	2.23	2.14
60	40	2.50	2.25	2.20	2.24	2.30
80	20	2.50	2.15	2.05	2.05	2.19
100	0	2.53	1.93	2.03	2.28	2.19
		OSP additive				
0	100	2.38	2.15	2.20	2.03	2.19
20	80	2.55	2.60	2.13	2.18	2.37
40	60	2.53	2.30	2.15	2.28	2.32
60	40	2.43	2.18	2.40	2.28	2.29
80	20	2.43	2.08	2.19	2.15	2.21
100	0	2.68	2.53	2.33	2.18	2.43

Table 61. Magnesium in corn plant tissue at 2 months of age from plots fertilized in 1971 with various combinations of SCSP and CSP or OSP

Treatment 84 kg P/ha		Replication				Mean
SCSP	Additive	1	2	3	4	
------ % -------		---------- Mg, % ----------				
		CSP additive				
0	100	0.194	0.258	0.269	0.238	0.240
20	80	0.150	0.198	0.300	0.211	0.215
40	60	0.130	0.325	0.329	0.253	0.261
60	40	0.153	0.318	0.220	0.218	0.227
80	20	0.156	0.295	0.273	0.226	0.238
100	0	0.133	0.258	0.353	0.220	0.242
		OSP additive				
0	100	0.218	0.215	0.228	0.205	0.167
20	80	0.128	0.203	0.293	0.273	0.224
40	60	0.143	0.255	0.193	0.296	0.222
60	40	0.190	0.333	0.298	0.219	0.260
80	20	0.103	0.254	0.303	0.256	0.229
100	0	0.179	0.265	0.245	0.230	0.230

Table 62. Magnesium in corn ear-leaf tissue at 3 months of age from plots fertilized in 1971 with various combinations of SCSP and CSP or OSP

Treatment		Replication				Mean
84 kg P/ha		1	2	3	4	
SCSP	Additive					
------ % -------		---------- Mg, % ----------				
		CSP additive				
0	100	0.203	0.203	0.203	0.215	0.206
20	80	0.151	0.155	0.265	0.239	0.203
40	60	0.115	0.190	0.265	0.208	0.195
60	40	0.125	0.184	0.193	0.197	0.175
80	20	0.120	0.173	0.235	0.194	0.186
100	0	0.104	0.170	0.199	0.208	0.170
		OSP additive				
0	100	0.104	0.151	0.169	0.180	0.151
20	80	0.116	0.180	0.200	0.190	0.172
40	60	0.119	0.194	0.201	0.184	0.175
60	40	0.123	0.199	0.173	0.180	0.169
80	20	0.118	0.200	0.182	0.145	0.161
100	0	0.134	0.173	0.194	0.180	0.170

Table 63. Manganese in corn plant tissue at 2 months of age from plots fertilized in 1971 with various combinations of SCSP and CSP or OSP

Treatment		Replication				Mean
84 kg P/ha		1	2	3	4	
SCSP	Additive					
------ % -------		---------- Mn, ppm ----------				
		CSP additive				
0	100	623	280	395	230	384
20	80	525	435	455	540	489
40	60	498	438	290	233	365
60	40	595	200	350	448	398
80	20	320	245	385	276	306
100	0	595	460	498	293	462
		OSP additive				
0	100	550	620	230	398	450
20	80	463	540	270	455	432
40	60	525	420	290	315	388
60	40	607	460	265	485	453
80	20	525	540	400	255	430
100	0	530	358	450	446	446

Table 64. Manganese in corn ear-leaf tissue at 3 months of age from plots fertilized in 1971 with various combinations of SCSP and CSP or OSP

Treatment		Replication				Mean
84 kg P/ha		1	2	3	4	
SCSP	Additive					
------ % ------		---------- Mn, ppm ----------				
		CSP additive				
0	100	495	250	365	285	349
20	80	540	340	475	420	444
40	60	685	465	265	395	453
60	40	655	255	242	500	413
80	20	745	395	280	463	471
100	0	715	285	450	311	440
		OSP additive				
0	100	635	395	253	540	456
20	80	660	154	189	395	350
40	60	665	465	385	280	449
60	40	660	365	225	545	449
80	20	663	420	343	212	410
100	0	745	291	370	265	418

Table 65. Analyses of variance of corn responses, soil and tissue P data of fertilization with mixture of coated and non-coated P fertilizers, 1971

Source	df	Mean squares		
		Stalk and ear responses		
		Stalk no.	Ear no.	Ears/stalk
Blocks	3	22.5764	23.5833	0.1246
Mixture				
Linear	1	0.0446	0.1786	0.0110
Quadratic	1	0.8571	0.0015	0.0913
Cubic	1	20.0694	0.4340	1.2004
Quartic	1	0.6429	1.2902	0.3437
Quintic	1	40.5734	11.0124	0.8607
Source (S)	1	1.6875	52.0833*	2.7843
Mixture x S	5	0.7538	6.8833	0.5545
Error	33	12.2431	10.4167	0.4550
		Yield responses		
		Ave. ear wt.	Kernel wt.	Yield
Blocks	3	589,523.38**	5.1220	8,961,046**
Mixture				
Linear	1	432.08	12.1021	5,596
Quadratic	1	20,204.94	3.3018	10,977
Cubic	1	57,363.93	0.0815	3,047,691*
Quartic	1	370.36	1.7480	125,293
Quintic	1	23,455.84	0.0572	9,794
Source (S)	1	21,501.18	0.0066	543,571
Mixture x S	5	36,685.75	6.2314	373,907
Error	33	49,936.24	3.1111	618,938

Table 65. Continued

Source	df	Mean squares		
		Soil and tissue P responses		
		Soil P June	Tissue P at pre-silking+	Tissue P at late silking‡
Blocks	3	1,243.21	0.2712	0.5381*
Mixture				
Linear	1	1,013.19	0.9929*	0.0000
Quadratic	1	4,768.54	0.1240	0.2489
Cubic	1	1,048.06	0.1793	0.2033
Quartic	1	758.52	0.0718	0.0166
Quintic	1	24.31	0.2123	1.0443*
Source (S)	1	1,731.00	0.0675	0.0750
Mixture x S	5	1,977.43	0.0946	0.2986
Error	33	1,439.11	0.1681	0.1839

+ Mean squares must be multiplied by 10^{-2}.
‡ Mean squares must be multiplied by 10^{-3}.
* Significant at the 5% level.
** Significant at the 1% level.

Table 66. Correlation coefficients from study of mixtures of coated and non-coated P fertilizers, 1971

Nutrient	Yield		Tissue P			
			Pre-silking stage		Late-silking stage	
	Linear r	Multiple r	Linear r	Multiple r	Linear r	Multiple r
Soil sampled in June 1971						
P	-0.1373	0.4334+				
Soil sampled in September 1971						
P	0.0415	0.1037				
Tissue at pre-silking stage						
P	0.3322*	0.3325		-0.2053		0.3807+
Al	0.2032		0.1138	-0.0399	0.1818	0.0765
Fe	-0.0957		-0.1261	0.1878	0.1555	0.1899
Ca	0.3290*		0.1304	-0.0367	0.1810	0.2223
K	0.1225		0.4092*	-0.1751	0.4143	0.2290
Mg	0.1611		-0.2017	-0.0285	0.1210	0.2130
Mn	-0.1628		-0.0423	-0.1490	0.0487	0.1710
Zn	0.1661		-0.0696	0.1709	0.1801	0.2020
Cu	0.0496		-0.4391*	-0.1381	0.4391	0.1496
Tissue at late-silking stage						
P	0.0288	0.1948	-0.2053		0.3807+	
Al	0.2452			0.1931		0.3222
Fe	0.2324			0.2262		0.2531
Ca	-0.1902			0.0310		0.0337
K	0.0775			0.0615		0.0615
Mg	0.1321			-0.1518		0.2285
Mn	0.0493			0.0001		0.0988
Si	-0.1194			0.0409		0.0418

+ Significant increase over that of linear r value due to inclusion of quadratic term in equation.

* Significant at the 5% level.

** Significant at the 1% level.

Table 67. Rainfall on field plots in 1972 from time of planting until corn harvest

Time after planting weeks	Rainfall per week cm
1	0.30
2	4.85
3	0.89
4	2.03
5	1.96
6	0.00
7	0.08
8	12.09
9	0.38
10	0.38
11	0.46
12	3.12
13	3.53
14	10.85
15	3.18
16	0.69
17	0.64
18	1.70
19	2.57
20	0.33
21	2.57
22	2.29
23	7.24

Table 68. Corn yields in 1972 from residual and applied CSP and SCSP at various rates

P treatment		Replication				Mean
1971	1972	1	2	3	4	
---- kg/ha ----		---------- Yield, kg/ha ----------				
		Check				
0	0	4,210	3,920	5,750	4,100	4,500
0	0	5,490	6,760	6,300	3,410	5,490
		CSP (20.1% P)				
28	14	6,210	7,590	8,690	8,210	7,660
28	0	8,830	9.730	8,830	7,800	8,830
56	28	10,500	8,070	7,800	8,140	8,630
56	0	8,000	8,560	8,560	8,000	8,280
84	42	9,110	8,560	8,900	10,100	9,180
84	0	9,180	9,110	9,730	8,690	9,180
112	56	7,660	9.450	9,660	8,420	8,830
112	0	7,940	9,040	10,000	8,760	8,970
140	70	8,350	8,560	8,760	9,180	8,690
140	0	7,940	8,630	8,490	8,630	8,418
168	0	8,630	9,660	8,970	8,140	8,830
168	0	9,250	9,590	8,690	7,250	8,690
196	0	7,730	8,490	8,070	7,310	7.940
196	0	6,420	9,730	8,280	7,800	8,070
		SCSP (15.5% P)				
28	14	8,350	10,000	8,350	6,900	8,420
28	0	8,490	8,690	11,500	7,590	9,110
56	28	9,380	9,380	8,760	9,040	9,180
56	0	8,630	8,690	7,380	7,521	8,073
84	42	6,610	8,070	9,110	8,560	8,070
84	0	7,730	9,450	9,040	8,140	8,630
112	56	7,870	9,320	8,760	8,210	8,560
112	0	6,970	7,380	9,590	8,000	8,000
140	70	8,690	8,690	8,830	8,070	8,560
140	0	8,140	8,690	7,590	8,630	8,280

Table 68. Continued

P treatment		Replication				Mean
1971	1972	1	2	3	4	
---- kg/ha ----		---------- Yield, kg/ha ----------				
		SCSP (14.8% P)				
28	14	8,070	7,870	7,870	7,730	7,870
28	0	6,970	8,830	6,520	6,900	7,310
56	28	7,940	8,350	8,000	8,970	8,350
56	0	6,660	9,320	7,660	8,490	8,000
84	42	9,520	9,590	8,830	9,180	9,320
84	0	7,660	11,700	9,320	7,590	9,040
112	56	9,870	8,280	8,970	8,140	8,830
112	0	8,900	8,350	8,970	7,730	8,490
140	70	8,900	9,870	9,180	9,180	9,320
140	0	9,590	9,380	9,250	8,280	9,110

Table 69. Phosphorus extracted by 0.03N NH_4F in 0.1N HCl from soil samples taken 12 months after fertilization in 1971 with several rates of CSP and two SCSP fertilizers using band placement

P treatment		Replication				Mean
1971	1972	1	2	3	4	
kg/ha		P, µg/g soil				
		Check				
0	0	5.6	6.0	5.8	4.9	5.6
		CSP (20.1% P)				
28	0	11.0	8.9	16.0	11.5	11.9
56	0	7.7	11.0	8.1	21.6	12.1
84	0	17.4	10.4	13.7	28.0	17.4
112	0	18.1	14.9	18.9	20.5	18.1
140	0	25.9	18.2	32.4	41.1	29.4
168	0	13.2	13.2	16.8	13.2	14.1
196	0	26.6	24.6	30.1	14.8	24.0
		SCSP (15.5% P)				
28	0	7.7	15.2	16.2	7.9	11.8
56	0	15.4	10.4	10.5	13.7	12.5
84	0	9.2	19.6	26.5	9.9	16.3
112	0	10.5	21.0	11.7	11.9	13.8
140	0	16.7	10.9	19.8	18.2	16.4
		SCSP (14.8% P)				
28	0	8.2	16.0	7.2	6.9	9.6
56	0	23.1	16.2	6.3	19.1	16.2
84	0	8.7	17.1	8.4	10.6	11.2
112	0	10.5	22.5	16.2	16.7	16.5
140	0	15.9	13.9	15.0	14.4	14.8

Table 70. Phosphorus extracted by 0.03N NH_4F in 0.1N HCl from soil samples taken 3 months after fertilization in 1972 from residual and applied CSP and SCSP at various rates

P treatment		Replication				Mean
1971	1972	1	2	3	4	
---- kg/ha ----		---------- P, µg/g soil ----------				
		Check				
0	0	4.8	6.2	7.4	5.4	6.0
0	0	5.8	6.5	6.6	4.4	5.8
		CSP (20.1% P)				
28	14	22.0	25.4	24.6	29.5	25.4
28	0	13.2	5.5	11.8	13.8	11.1
56	28	87.0	27.2	52.5	85.5	63.1
56	0	8.9	6.3	9.2	8.8	8.3
84	42	119.0	40.3	90.0	71.5	80.2
84	0	52.5	7.6	11.3	11.2	20.7
112	56	105.0	105.0	85.0	124.0	105.0
112	0	19.9	20.9	10.8	12.9	16.1
140	70	202.0	195.0	209.0	173.0	195.0
140	0	16.6	8.4	11.5	10.5	11.8
168	0	23.7	27.6	16.3	17.2	21.2
168	0	17.3	22.3	29.6	16.7	21.5
196	0	45.5	17.7	40.3	22.4	31.3
196	0	22.6	37.2	36.3	32.0	32.0
		SCSP (15.5% P)				
28	14	34.6	23.7	38.1	40.4	34.2
28	0	7.8	9.9	5.8	7.8	7.8
56	28	65.5	69.5	76.0	67.0	69.5
56	0	12.4	9.5	6.6	11.0	9.9
84	42	60.0	61.1	51.9	71.5	61.1
84	0	14.8	20.2	24.6	11.5	17.8
112	56	126.0	132.0	155.0	111.0	131.0
112	0	11.5	23.5	12.8	13.8	15.4
140	70	68.5	107.0	91.5	131.0	99.5
140	0	15.9	10.5	19.2	10.7	14.1

Table 70. Continued

P treatment		Replication				Mean
1971	1972	1	2	3	4	
---- kg/ha ----		---------- P, µg/g soil ----------				
		SCSP (14.8% P)				
28	14	20.0	37.0	25.3	27.4	27.4
28	0	6.1	10.1	9.4	7.9	8.4
56	28	52.0	81.0	99.0	45.8	69.5
56	0	10.0	22.3	8.2	14.6	13.8
84	42	109.0	124.0	67.0	103.0	101.0
84	0	17.0	17.5	8.2	10.7	13.3
112	56	150.0	135.0	151.0	104.0	135.0
112	0	16.8	10.4	16.5	12.9	14.2
140	70	170.0	98.0	249.0	202.0	180.0
140	0	13.5	11.2	23.3	15.1	15.8

Table 71. Phosphorus extracted by 1N NH_4OAc from soil samples taken 3 months after fertilization in 1972 from residual and applied CSP and SCSP at various rates

P treatment		Replication				Mean
1971	1972	1	2	3	4	
---- kg/ha ----		---------- P, µg/g soil ----------				
		Check				
0	0	0.45	0.20	0.20	0.20	0.26
0	0	0.45	0.20	0.20	0.45	0.33
		CSP (20.1% P)				
28	14	0.65	1.10	0.45	1.10	0.83
28	0	0.45	0.20	0.20	0.45	0.33
56	28	6.10	3.65	1.75	6.10	4.40
56	0	0.45	0.20	0.20	0.65	0.38
84	42	7.40	5.95	5.65	4.80	5.95
84	0	0.45	0.45	0.20	0.65	0.45
112	56	8.00	7.85	5.65	10.45	8.00
112	0	0.45	0.65	0.45	0.65	0.55
140	70	7.40	8.20	10.05	7.00	8.20
140	0	0.65	0.45	0.45	0.65	0.55
168	0	0.45	0.65	0.20	0.65	0.49
168	0	0.45	0.45	0.45	0.45	0.45
196	0	0.65	0.65	0.65	0.85	0.70
196	0	0.20	0.45	0.20	0.45	0.33
		SCSP (15.5% P)				
28	14	3.50	0.85	2.20	2.60	2.29
28	0	0.20	0.45	0.20	0.65	0.38
56	28	0.85	0.65	1.67	3.50	1.67
56	0	0.20	0.45	0.65	0.65	0.49
84	42	3.05	6.10	7.40	6.10	5.66
84	0	0.45	0.85	0.45	0.65	0.60
112	56	7.72	11.35	6.55	5.25	7.72
112	0	0.45	0.45	0.45	0.65	0.50
140	70	0.65	0.45	0.85	0.65	0.65
140	0	0.45	0.45	0.65	0.45	0.50

Table 71. Continued

P treatment		Replication				Mean
1971	1972	1	2	3	4	
---- kg/ha ----		---------- P, µg/g soil ----------				
		SCSP (14.8% P)				
28	14	0.45	1.30	0.65	0.45	0.71
28	0	0.20	0.20	0.20	0.45	0.26
56	28	1.10	5.25	2.40	0.85	2.40
56	0	0.20	0.45	0.45	0.45	0.39
84	42	3.95	3.95	2.20	4.35	3.61
84	0	0.45	0.45	0.45	0.45	0.45
112	56	4.80	2.20	6.10	5.65	4.69
112	0	0.45	0.20	0.65	0.45	0.45
140	70	7.40	3.50	14.40	10.90	9.05
140	0	0.65	0.45	1.10	0.65	0.71

Table 72. Phosphorus extracted by 0.03N NH_4F in 0.1N HCl from soil samples taken 5 months after 1972 fertilization from residual and applied CSP and SCSP at various rates

P treatment		Replication				Mean
1971	1972	1	2	3	4	
kg/ha		P, µg/g soil				
		Check				
0	0	4.9	4.8	5.4	6.1	5.3
0	0	5.4	5.8	6.1	4.2	5.4
		CSP (20.1% P)				
28	14	28.0	13.0	24.5	27.0	23.1
28	0	9.4	5.0	10.4	11.1	9.0
56	28	92.5	52.0	44.1	48.8	59.4
56	0	11.1	6.5	8.3	7.0	8.2
84	42	94.5	81.3	73.5	76.0	81.3
84	0	9.4	11.4	8.3	8.4	9.4
112	56	124.0	97.0	99.5	107.0	107.0
112	0	13.0	11.3	10.9	7.9	10.8
140	70	80.0	178.0	120.0	120.0	125.0
140	0	9.6	11.6	8.2	8.3	9.4
168	0	16.9	25.5	14.6	19.4	19.1
168	0	10.5	15.8	11.1	13.3	12.7
196	0	20.5	13.3	29.0	19.5	20.6
196	0	23.9	9.5	13.4	6.9	13.4
		SCSP (15.5% P)				
28	14	11.2	10.6	10.8	9.8	10.6
28	0	7.9	10.4	7.7	6.2	8.1
56	28	56.0	31.1	66.0	45.3	49.6
56	0	6.5	6.9	10.0	11.0	8.6
84	42	40.4	44.0	40.5	76.0	50.2
84	0	10.1	9.2	19.0	8.1	11.6
112	56	85.5	62.5	85.5	52.0	71.4
112	0	7.4	11.4	12.3	7.4	9.6
140	70	91.0	107.0	55.5	85.0	84.6
140	0	19.0	10.1	10.9	8.7	12.2

Table 72. Continued

P treatment		Replication				Mean
1971	1972	1	2	3	4	
kg/ha		P, µg/g soil				
		SCSP (14.8% P)				
28	14	21.2	32.5	23.4	16.6	23.4
28	0	4.4	8.8	4.9	5.8	6.0
56	28	23.0	21.3	47.0	52.0	35.8
56	0	5.7	10.5	8.2	6.7	7.8
84	42	112.0	65.0	87.0	91.5	88.9
84	0	5.0	10.6	9.4	5.6	7.7
112	56	69.0	80.5	94.0	69.0	78.1
112	0	21.7	7.9	13.8	11.7	13.8
140	70	121.0	113.0	189.0	141.0	141.0
140	0	12.0	13.1	16.0	8.5	12.4

Table 73. The pH of soil samples taken 3 months after fertilization in 1972 from residual and applied CSP and SCSP at various rates

P treatment		Replication				Mean
1971	1972	1	2	3	4	
kg/ha		pH				
		Check				
0	0	5.2	5.2	5.6	5.7	5.4
0	0	5.1	5.4	5.6	5.7	5.5
		CSP (20.1% P)				
28	14	5.3	5.5	5.5	5.7	5.5
28	0	5.4	5.4	5.5	5.7	5.5
56	28	5.2	5.5	5.6	5.7	5.4
56	0	5.1	5.1	5.5	5.7	5.4
84	42	5.2	5.5	5.6	5.5	5.5
84	0	5.0	5.5	5.8	5.6	5.5
112	56	5.2	5.5	5.7	5.7	5.5
112	0	5.2	5.6	5.7	5.6	5.5
140	70	5.3	5.5	5.6	5.5	5.5
140	0	5.3	5.3	5.6	5.6	5.5
168	0	5.0	5.3	5.7	5.8	5.5
168	0	5.2	5.3	5.5	5.6	5.4
196	0	5.2	5.1	5.5	5.5	5.3
196	0	5.1	5.3	5.5	5.6	5.4
		SCSP (15.5% P)				
28	14	5.0	5.5	5.4	5.5	5.4
28	0	5.1	5.3	5.6	5.7	5.4
56	28	5.2	5.3	5.3	5.5	5.3
56	0	5.1	5.2	5.7	5.5	5.4
84	42	5.0	5.2	5.5	5.4	5.3
84	0	5.2	5.2	5.4	5.6	5.4
112	56	5.3	5.3	5.3	5.6	5.4
112	0	5.3	5.5	5.5	5.7	5.5
140	70	5.3	5.6	5.5	5.6	5.5
140	0	5.3	5.7	5.5	5.5	5.5

Table 73. Continued

P treatment		Replication				Mean
1971	1972	1	2	3	4	
---- kg/ha ----		---------- pH ----------				
		SCSP (14.8% P)				
28	14	5.1	5.3	5.6	5.7	5.4
28	0	5.1	5.5	5.6	5.6	5.5
56	28	5.2	5.2	5.6	5.7	5.4
56	0	5.3	5.7	5.6	5.7	5.6
84	42	5.4	5.3	5.6	5.3	5.4
84	0	5.2	5.4	5.6	5.3	5.4
112	56	5.1	5.5	5.4	5.6	5.4
112	0	5.2	5.5	5.5	5.6	5.5
140	70	5.1	5.3	5.4	5.5	5.3
140	0	5.3	5.6	5.5	5.6	5.5

Table 74. Calcium extracted by 1N NH_4OAc from soil samples taken 3 months after fertilization in 1972 from residual and applied CSP and SCSP at various rates

P treatment		Replication				Mean
1971	1972	1	2	3	4	
kg/ha		Ca, ppm				
		Check				
0	0	160	190	175	125	163
0	0	140	140	160	140	145
		CSP (20.1% P)				
28	14	190	235	160	265	249
28	0	160	190	160	190	175
56	28	160	205	250	265	220
56	0	50	85	175	190	125
84	42	205	175	205	190	194
84	0	100	190	220	140	163
112	56	110	295	315	280	250
112	0	100	235	190	140	166
140	70	205	160	295	295	239
140	0	100	160	205	160	156
168	0	110	125	220	220	169
168	0	140	125	140	175	145
196	0	140	235	140	160	169
196	0	140	179	140	160	154
		SCSP (15.5% P)				
28	14	140	160	235	235	193
28	0	100	125	175	133	133
56	28	125	125	142	175	142
56	0	70	110	113	160	113
84	42	220	235	235	205	224
84	0	175	175	110	160	155
112	56	190	265	235	265	239
112	0	125	160	160	205	163
140	70	140	295	205	205	211
140	0	140	235	175	160	178

Table 74. Continued

P treatment		Replication				Mean
1971	1972	1	2	3	4	
---- kg/ha ----		---------- Ca, ppm ----------				
		SCSP (14.8% P)				
28	14	160	190	220	175	186
28	0	110	220	140	175	161
56	28	140	190	330	250	228
56	0	125	295	175	220	204
84	42	250	235	205	205	224
84	0	85	128	190	110	128
112	56	175	205	235	250	216
112	0	100	175	140	190	151
140	70	205	265	345	295	278
140	0	110	265	205	205	196

Table 75. Potassium extracted by 1N NH_4OAc from soil samples taken 3 months after fertilization in 1972 from residual and applied CSP and SCSP at various rates

P treatment		Replication				Mean
1971	1972	1	2	3	4	
---- kg/ha ----		---------- K, ppm ----------				
		Check				
0	0	52	68	100	60	70
0	0	62	76	95	60	73
		CSP (20.1% P)				
28	14	100	76	81	84	85
28	0	108	96	92	103	100
56	28	86	40	78	81	71
56	0	48	62	76	64	63
84	42	54	68	81	64	67
84	0	76	92	98	64	83
112	56	62	57	92	46	64
112	0	92	57	103	62	79
140	70	68	73	60	70	68
140	0	98	70	98	68	84
168	0	81	52	86	70	72
168	0	76	57	92	73	75
196	0	60	52	70	84	67
196	0	95	86	86	81	87
		SCSP (15.5% P)				
28	14	43	48	78	98	67
28	0	73	57	89	86	76
56	28	60	38	55	68	55
56	0	81	64	106	64	79
84	42	89	84	70	54	74
84	0	68	81	92	73	79
112	56	78	68	64	57	67
112	0	92	78	76	70	79
140	70	103	92	92	62	87
140	0	103	48	108	57	79

Table 75. Continued

P treatment		Replication				Mean
1971	1972	1	2	3	4	
---- kg/ha ----		---------- K, ppm ----------				
		SCSP (14.8% P)				
28	14	64	54	76	40	59
28	0	78	64	84	57	71
56	28	73	62	84	57	69
56	0	92	114	112	73	98
84	42	106	60	86	48	75
84	0	84	75	89	52	75
112	56	60	57	64	48	57
112	0	84	57	89	62	73
140	70	64	76	76	62	70
140	0	64	92	114	73	86

Table 76. Magnesium extracted by 1N NH_4OAc from soil samples taken 3 months after fertilization in 1972 from residual and applied CSP and SCSP at various rates

P treatment		Replication				Mean
1971	1972	1	2	3	4	
---- kg/ha ----		---------- Mg, ppm ----------				
		Check				
0	0	48	56	72	76	63
0	0	50	61	61	82	64
		CSP (20.1% P)				
28	14	50	61	61	82	64
28	0	48	61	61	76	62
56	28	48	66	66	76	64
56	0	30	42	61	72	51
84	42	34	66	61	72	58
84	0	42	72	88	66	70
112	56	42	82	88	66	71
112	0	38	82	82	72	69
140	70	50	61	88	72	68
140	0	42	56	61	66	56
168	0	38	50	82	88	65
168	0	38	50	56	76	55
196	0	50	61	61	61	58
196	0	50	66	61	61	60
		SCSP (15.5% P)				
28	14	38	66	72	61	59
28	0	38	61	72	88	65
56	28	48	61	57	61	57
56	0	42	56	105	82	71
84	42	56	56	76	76	66
84	0	50	61	56	61	57
112	56	56	48	66	88	62
112	0	48	56	66	76	62
140	70	42	88	76	82	72
140	0	42	82	72	72	67

Table 76. Continued

P treatment		Replication				Mean
1971	1972	1	2	3	4	
---- kg/ha ----		---------- Mg, ppm ----------				
		SCSP (14.8% P)				
28	14	42	61	72	94	67
28	0	42	56	61	72	58
56	28	48	38	76	88	63
56	0	48	66	66	82	66
84	42	72	61	56	66	64
84	0	50	54	61	50	54
112	56	50	61	61	66	60
112	0	48	66	61	72	62
140	70	48	66	88	66	67
140	0	50	82	82	66	70

Table 77. Phosphorus in corn ear-leaf tissue at 3 months of age in 1972 from residual and applied CSP and SCSP plots at various rates

P treatment		Replication				Mean
1971	1972	1	2	3	4	
---- kg/ha ----		---------- P, % ----------				
		Check				
0	0	0.193	0.173	0.204	0.193	0.191
0	0	0.202	0.205	0.204	0.198	0.202
		CSP (20.1% P)				
28	14	0.308	0.248	0.275	0.300	0.283
28	0	0.274	0.234	0.295	0.328	0.283
56	28	0.400	0.318	0.323	0.293	0.334
56	0	0.279	0.274	0.311	0.273	0.284
84	42	0.318	0.309	0.335	0.308	0.318
84	0	0.385	0.276	0.278	0.275	0.304
112	56	0.301	0.370	0.335	0.277	0.321
112	0	0.311	0.340	0.300	0.260	0.303
140	70	0.304	0.306	0.320	0.344	0.319
140	0	0.279	0.338	0.318	0.299	0.309
168	0	0.331	0.373	0.308	0.345	0.339
168	0	0.334	0.338	0.340	0.350	0.341
196	0	0.300	0.320	0.355	0.360	0.334
196	0	0.299	0.320	0.389	0.308	0.329
		SCSP (15.5% P)				
28	14	0.334	0.244	0.264	0.224	0.267
28	0	0.271	0.293	0.246	0.248	0.265
56	28	0.340	0.334	0.293	0.333	0.325
56	0	0.296	0.270	0.289	0.318	0.294
84	42	0.280	0.293	0.368	0.323	0.316
84	0	0.278	0.289	0.360	0.273	0.300
112	56	0.348	0.370	0.301	0.299	0.330
112	0	0.298	0.338	0.339	0.266	0.310
140	70	0.320	0.370	0.313	0.280	0.321
140	0	0.343	0.323	0.360	0.321	0.337

Table 77. Continued

P treatment		Replication				Mean
1971	1972	1	2	3	4	
kg/ha		P, %				
		SCSP (14.8% P)				
28	14	0.261	0.286	0.288	0.204	0.260
28	0	0.250	0.296	0.258	0.258	0.264
56	28	0.270	0.299	0.300	0.295	0.291
56	0	0.193	0.363	0.256	0.351	0.291
84	42	0.363	0.334	0.315	0.308	0.330
84	0	0.295	0.340	0.290	0.253	0.295
112	56	0.301	0.388	0.368	0.245	0.326
112	0	0.283	0.311	0.305	0.290	0.297
140	70	0.400	0.329	0.350	0.331	0.353
140	0	0.393	0.343	0.306	0.310	0.338

Table 78. Aluminum in corn ear-leaf tissue at 3 months of age in 1972 from residual and applied CSP and SCSP plots at various rates

P treatment		Replication				Mean
1971	1972	1	2	3	4	
---- kg/ha ----		---------- Al, ppm ----------				
		Check				
0	0	100	150	125	125	125
0	0	175	188	100	150	153
		CSP (20.1% P)				
28	14	150	200	125	150	156
28	0	250	150	125	100	156
56	28	250	175	150	150	181
56	0	200	300	250	225	244
84	42	200	200	250	175	206
84	0	200	300	125	150	194
112	56	175	225	150	175	181
112	0	250	225	150	175	200
140	70	175	150	150	175	163
140	0	175	200	350	200	231
168	0	225	125	200	200	188
168	0	175	150	225	250	200
196	0	300	225	125	150	200
196	0	250	175	150	150	181
		SCSP (15.5% P)				
28	14	200	175	200	200	194
28	0	225	100	200	150	169
56	28	175	175	175	125	163
56	0	150	150	200	125	156
84	42	125	200	100	150	144
84	0	200	150	125	125	150
112	56	175	175	175	175	175
112	0	200	200	125	250	194
140	70	200	200	225	175	200
140	0	150	175	150	200	169

Table 78. Continued

P treatment 1971	P treatment 1972	Replication 1	2	3	4	Mean
kg/ha	kg/ha	Al, ppm				
		SCSP (14.8% P)				
28	14	225	175	200	175	194
28	0	150	150	225	150	169
56	28	275	100	175	200	188
56	0	225	125	225	150	181
84	42	150	150	150	175	156
84	0	225	175	150	150	170
112	56	200	200	200	150	188
112	0	150	150	200	150	163
140	70	175	200	125	150	163
140	0	150	250	125	150	169

Table 79. Iron in corn ear-leaf tissue at 3 months of age in 1972 from residual and applied CSP and SCSP at various rates

P treatment		Replication				Mean
1971	1972	1	2	3	4	
kg/ha		Fe, ppm				
		Check				
0	0	160	165	145	143	153
0	0	185	173	140	160	165
		CSP (20.1% P)				
28	14	218	145	153	145	165
28	0	223	153	160	190	182
56	28	213	178	143	158	173
56	0	178	223	223	198	206
84	42	215	183	196	190	196
84	0	170	163	140	198	168
112	56	183	223	190	165	190
112	0	228	198	295	173	200
140	70	180	138	140	133	148
140	0	173	213	270	168	206
168	0	218	270	175	230	223
168	0	198	160	200	208	192
196	0	215	203	143	170	183
196	0	220	275	153	165	203
		SCSP (15.5% P)				
28	14	215	163	200	180	190
28	0	245	165	173	175	190
56	28	223	173	158	113	167
56	0	263	206	185	170	206
84	42	170	213	110	155	162
84	0	205	163	135	155	165
112	56	195	190	170	158	178
112	0	193	220	165	130	177
140	70	203	180	190	153	182
140	0	180	170	178	200	182

Table 79. Continued

P treatment 1971	P treatment 1972	Replication 1	Replication 2	Replication 3	Replication 4	Mean
kg/ha	kg/ha	Fe, ppm				
		SCSP (14.8% P)				
28	14	230	153	198	148	182
28	0	203	160	193	140	174
56	28	190	165	153	180	172
56	0	178	195	210	153	184
84	42	168	183	173	168	173
84	0	203	180	183	155	180
112	56	230	255	158	137	195
112	0	190	183	163	163	175
140	70	203	175	120	170	147
140	0	225	195	185	163	192

Table 80. Calcium in corn ear-leaf tissue at 3 months of age in 1972 from residual and applied CSP and SCSP plots at various rates

P treatment		Replication				Mean
1971	1972	1	2	3	4	
---- kg/ha ----		---------- Ca, % ----------				
		Check				
0	0	0.250	0.250	0.308	0.308	0.279
0	0	0.325	0.330	0.283	0.300	0.310
		CSP (20.1% P)				
28	14	0.383	0.375	0.350	0.350	0.365
28	0	0.358	0.325	0.358	0.358	0.350
56	28	0.383	0.390	0.383	0.408	0.391
56	0	0.343	0.358	0.443	0.450	0.399
84	42	0.368	0.408	0.390	0.433	0.399
84	0	0.368	0.358	0.375	0.358	0.365
112	56	0.393	0.458	0.433	0.443	0.432
112	0	0.393	0.408	0.375	0.418	0.399
140	70	0.375	0.425	0.375	0.475	0.413
140	0	0.333	0.418	0.383	0.425	0.390
168	0	0.375	0.418	0.383	0.418	0.399
168	0	0.350	0.458	0.383	0.468	0.415
196	0	0.358	0.400	0.400	0.458	0.404
196	0	0.325	0.418	0.425	0.433	0.400
		SCSP (15.5% P)				
28	14	0.400	0.375	0.375	0.375	0.381
28	0	0.343	0.400	0.318	0.358	0.355
56	28	0.418	0.408	0.400	0.408	0.409
56	0	0.293	0.343	0.368	0.368	0.343
84	42	0.418	0.383	0.400	0.400	0.400
84	0	0.393	0.318	0.418	0.325	0.364
112	56	0.400	0.425	0.418	0.450	0.423
112	0	0.343	0.325	0.375	0.383	0.357
140	70	0.318	0.458	0.433	0.375	0.396
140	0	0.393	0.393	0.408	0.408	0.401

Table 80. Continued

P treatment		Replication				Mean
1971	1972	1	2	3	4	
---- kg/ha ----		---------- Ca, % ----------				
		SCSP (14.8% P)				
28	14	0.308	0.358	0.408	0.425	0.375
28	0	0.343	0.400	0.358	0.400	0.375
56	28	0.383	0.375	0.408	0.468	0.409
56	0	0.308	0.425	0.333	0.408	0.369
84	42	0.418	0.433	0.418	0.468	0.434
84	0	0.343	0.383	0.383	0.393	0.376
112	56	0.400	0.433	0.408	0.425	0.417
112	0	0.343	0.383	0.375	0.458	0.390
140	70	0.400	0.450	0.475	0.493	0.455
140	0	0.425	0.408	0.393	0.450	0.419

Table 81. Potassium in corn ear-leaf tissue at 3 months of age in 1972 from residual and applied CSP and SCSP plots at various rates

P treatment		Replication				Mean
1971	1972	1	2	3	4	
---- kg/ha ----		---------- K, % ----------				
		Check				
0	0	1.93	1.88	1.80	1.99	1.90
0	0	1.93	1.89	1.80	1.98	1.90
		CSP (20.1% P)				
28	14	1.95	1.88	2.01	1.90	1.94
28	0	2.18	2.20	1.98	2.01	2.09
56	28	2.28	2.08	1.81	1.95	2.03
56	0	2.15	2.05	2.15	2.05	2.10
84	42	2.11	1.90	2.08	1.98	2.02
84	0	1.83	2.18	1.99	1.68	1.92
112	56	2.10	2.10	1.98	1.75	1.98
112	0	2.25	2.23	1.88	1.75	2.03
140	70	2.25	1.88	1.93	1.78	1.96
140	0	2.11	2.05	1.88	1.78	1.96
168	0	2.15	1.95	2.03	1.80	1.98
168	0	2.11	1.98	2.03	1.93	2.01
196	0	2.28	1.93	1.88	1.99	2.02
196	0	2.28	2.13	1.98	1.90	2.07
		SCSP (15.5% P)				
28	14	2.01	1.85	2.01	2.05	1.98
28	0	2.08	1.85	1.95	1.90	1.95
56	28	2.23	2.05	2.10	1.98	2.09
56	0	2.01	1.93	1.98	1.99	1.98
84	42	1.93	1.95	1.90	1.90	1.92
84	0	2.20	2.05	1.78	1.85	1.97
112	56	2.30	2.05	1.98	1.58	1.98
112	0	2.13	2.20	1.98	1.78	2.02
140	70	2.13	2.03	2.05	1.85	2.02
140	0	2.08	2.08	1.98	1.95	2.02

Table 81. Continued

P treatment		Replication				Mean
1971	1972	1	2	3	4	
---- kg/ha ----		---------- K, % ----------				
		SCSP (14.8% P)				
28	14	1.98	2.10	2.03	1.73	1.96
28	0	2.11	2.11	2.18	1.98	2.10
56	28	2.15	1.88	2.03	1.78	1.96
56	0	2.08	2.13	2.05	1.98	2.06
84	42	2.18	2.08	2.11	1.88	2.06
84	0	2.08	2.01	1.99	1.83	1.98
112	56	2.18	2.03	2.11	1.88	2.05
112	0	2.18	2.00	1.93	1.99	2.03
140	70	2.08	1.85	1.88	1.85	1.92
140	0	2.13	2.03	1.95	1.85	1.99

Table 82. Magnesium in corn ear-leaf tissue at 3 months of age in 1972 from residual and applied CSP and SCSP plots at various rates

P treatment		Replication				Mean
1971	1972	1	2	3	4	
---- kg/ha ----		---------- Mg, % ----------				
		Check				
0	0	0.238	0.295	0.318	0.278	0.282
0	0	0.225	0.295	0.270	0.263	0.263
		CSP (20.1% P)				
28	14	0.248	0.263	0.278	0.253	0.261
28	0	0.203	0.283	0.285	0.283	0.264
56	28	0.195	0.238	0.225	0.270	0.232
56	0	0.235	0.255	0.239	0.273	0.251
84	42	0.220	0.258	0.270	0.270	0.255
84	0	0.213	0.255	0.300	0.313	0.270
112	56	0.195	0.273	0.258	0.266	0.248
112	0	0.223	0.265	0.275	0.313	0.269
140	70	0.188	0.285	0.255	0.290	0.255
140	0	0.240	0.280	0.263	0.290	0.268
168	0	0.200	0.283	0.270	0.305	0.265
168	0	0.215	0.275	0.243	0.315	0.262
196	0	0.220	0.286	0.265	0.225	0.249
196	0	0.188	0.298	0.303	0.270	0.265
		SCSP (15.5% P)				
28	14	0.218	0.270	0.258	0.270	0.254
28	0	0.223	0.293	0.233	0.268	0.254
56	28	0.228	0.253	0.230	0.253	0.241
56	0	0.185	0.298	0.263	0.275	0.255
84	42	0.195	0.270	0.313	0.228	0.252
84	0	0.175	0.225	0.275	0.250	0.231
112	56	0.043	0.235	0.270	0.298	0.212
112	0	0.200	0.228	0.220	0.284	0.233
140	70	0.173	0.240	0.245	0.243	0.225
140	0	0.235	0.263	0.268	0.263	0.257

Table 82. Continued

P treatment 1971	P treatment 1972	Replication 1	Replication 2	Replication 3	Replication 4	Mean
kg/ha	kg/ha	Mg, %				
		SCSP (14.8% P)				
28	14	0.188	0.230	0.270	0.288	0.244
28	0	0.208	0.268	0.265	0.280	0.255
56	28	0.193	0.243	0.260	0.298	0.249
56	0	0.238	0.228	0.260	0.298	0.256
84	42	0.180	0.260	0.238	0.308	0.247
84	0	0.213	0.270	0.258	0.325	0.267
112	56	0.220	0.253	0.233	0.263	0.242
112	0	0.175	0.250	0.250	0.323	0.250
140	70	0.208	0.268	0.285	0.285	0.262
140	0	0.213	0.235	0.273	0.275	0.249

Table 83. Manganese in corn ear-leaf tissue at 3 months of age in 1972 from residual and applied CSP and SCSP plots at various rates

P treatment		Replication				Mean
1971	1972	1	2	3	4	
---- kg/ha ----		---------- Mn, ppm ----------				
		Check				
0	0	80	73	64	73	73
0	0	92	69	81	75	79
		CSP (20.1% P)				
28	14	142	87	97	73	100
28	0	118	88	88	78	93
56	28	150	100	100	95	111
56	0	106	105	90	92	98
84	42	144	92	102	100	110
84	0	152	92	92	80	104
112	56	150	100	88	62	100
112	0	194	104	75	78	113
140	70	139	87	95	90	103
140	0	144	97	106	88	109
168	0	155	101	92	75	106
168	0	161	100	92	75	107
196	0	137	80	75	88	95
196	0	137	90	83	92	101
		SCSP (15.5% P)				
28	14	156	111	106	90	116
28	0	135	75	83	97	98
56	28	161	64	101	95	105
56	0	127	83	90	73	93
84	42	144	104	85	117	113
84	0	137	95	69	80	95
112	56	181	111	92	100	121
112	0	106	92	92	69	90
140	70	159	123	103	88	118
140	0	123	85	83	154	111

Table 83. Continued

P treatment		Replication				Mean
1971	1972	1	2	3	4	
---- kg/ha ----		---------- Mn, ppm ----------				
		SCSP (14.8% P)				
28	14	142	104	100	52	100
28	0	123	101	90	64	95
56	28	169	109	103	78	115
56	0	142	78	87	66	93
84	42	142	120	106	114	121
84	0	132	95	90	94	103
112	56	139	115	92	79	106
112	0	186	97	100	71	114
140	70	111	118	92	102	106
140	0	120	101	75	71	92

Table 84. Analyses of variance of corn yield response, soil and tissue P data of P rate, source, and placement study, 1972

Source	df	Mean squares		
		Yield responses		
		Kernel wt.	Ave. ear wt.	Yield
Blocks	3	0.6916	312,003.79	4,709,377**
Rate (R)				
Linear	1	4.2398	8,991.40	3,804,350*
Quadratic	1	4.1408	26,562.71	1,871,866
Cubic	1	1.2324	6,728.12	862,863
Quartic	1	0.6823	120,612.39	2,430,266
Source	2	0.7562	5,575.91	380,010
Source x Rate	8	1.0190	45,306.80	1,750,152
Remainder	3	6.1055**	1,357,475.73**	25,494,479**
Error (a)	51	1.2549	72,034.11	823,287
Residual (Res)	1	1.7399	203,921.76*	1,839
Res x Rate				
Res x Linear	1	2.5452	16,131.03	611,434
Res x Quadratic	1	0.8836	390.93	176,359
Res x Cubic	1	0.4531	42,405.69	1,027,517
Res x Quartic	1	3.1193	55,285.82	1,900,533
Res x Source	2	1.1386	29,216.92	378,876
Res x Source x Rate	8	0.9891	38,002.57	486,256
Res x Remainder	3	5.5218*	106,970.96	1,474,954
Error (b)	54	1.3576	45,924.06	712,244

Table 84. Continued

Source	df	Mean squares		
		Soil and tissue P responses		
		Soil P June	Soil P August	Tissue P at late silking+
Blocks	3	262.56	62.18	3.5303
Rate (R)				
Linear	1	64,714.50**	35,456.14**	4.0016
Quadratic	1	22.48	41.44	0.2591
Cubic	1	87.60	254.31	0.3132
Quartic	1	413.33	134.56	0.0231
Source	2	1,419.90*	1,745.26**	0.0316
Source x Rate	8	1,238.05**	425.41	1.0076
Remainder	3			
Error (a)	51	407.75	208.76	1.6990
Residual (Res)	1	184,918.53**	104,335.62**	6.2785**
Res x Rate		13,999.52**	7,540.85**	0.9751
Res x Linear	1			
Res x Quadratic	1			
Res x Cubic	1			
Res x Quartic	1			
Res x Source	2	1,376.56*	1,927.12**	0.1464
Res x Source x Rate	8	1,413.28**	478.78*	0.5015
Res x Remainder	3			
Error (b)	54	271.81	187.48	0.8658

+ Mean squares must be multiplied by 10^{-3}.
* Significant at the 5% level.
** Significant at the 1% level.

Table 85. Correlation coefficients from study of P rate, source, and placement, 1972

Nutrient	Yield		Tissue P	
			Late-silking stage	
	Linear r	Multiple r	Linear r	Multiple r
	Soil sampled in March 1972			
P	0.2702*	0.4650+		
	Soil sampled in June 1972			
P	0.2623**	0.3025		
	Soil sampled in August 1972			
P	0.2763**	0.3029		
	Tissue at late-silking stage			
P	0.5753**	0.6568+		
Al	0.0754		0.0297	0.1480
Fe	0.1203		0.2122*	0.2210
Ca	0.4501**		0.5889**	0.6146*
K	0.0868		0.2016*	0.2052
Mg	-0.0060		-0.1595	0.1621
Mn	0.1238		0.2098*	0.2363

+ Significant increase over that of linear r value due to inclusion.

* Significant at the 5% level.

** Significant at the 1% level.

Table 86. Corn yields from plots fertilized in 1972 with various combinations of S-coated and non-coated CSP, urea, and KCl with and without plastic strip mulch

Treatment*			Replication				Mean
N source	K source	Plastic strip Mulch	1	2	3	4	
			Yield, kg/ha				
CSP (42 kg P/ha)							
Urea	KCl	Absent	10,070	9,450	9,590	11,250	10,070
Urea	KCl	Present	9,450	9,110	11,110	10,010	9,940
S-Urea	KCl	Absent	7,380	9,870	9,730	10,350	9,320
Urea	SKCl	Absent	9,040	10,010	9,108	12,210	10,070
S-Urea	SKCl	Absent	8,970	10,490	12,350	8,070	10,010
S-Urea	SKCl	Present	10,970	6,790	8,000	9,250	8,760
SCSP (42 kg P/ha)							
Urea	KCl	Absent	8,970	13,040	11,320	6,890	10,070
Urea	KCl	Present	10,490	9,450	7,180	7,310	8,630
S-Urea	KCl	Absent	8,280	10,010	12,560	10,350	10,280
Urea	SKCl	Absent	7,250	9,040	9,800	11,520	9,380
S-Urea	SKCl	Absent	8,690	7,940	8,280	10,490	8,832
S-Urea	SKCl	Present	8,690	10,900	9,730	9,380	9,660

* Uniform application of 168 kg N/ha and 140 kg K/ha from the sources.

Table 87. Phosphorus extracted by 0.03N NH_4F in 0.1N HCl from soil samples taken 3 months after fertilization in 1972 with various combinations of S-coated and non-coated CSP, urea, and KCl with and without plastic strip mulch

Treatment*			Replication				Mean
N source	K source	Plastic strip mulch	1	2	3	4	
			P, µg/g soil				
			CSP (42 kg P/ha)				
Urea	KCL	Absent	86.0	121.0	43.0	119.0	94.0
Urea	KCl	Present	114.0	131.0	75.5	122.0	111.0
S-Urea	KCl	Absent	63.0	126.0	103.0	122.0	104.0
Urea	SKCl	Absent	115.0	152.0	160.0	103.0	133.0
S-Urea	SKCl	Absent	122.0	54.0	127.0	100.0	101.0
S-Urea	SKCl	Present	167.0	54.0	78.0	163.0	116.0
			SCSP (42 kg P/ha)				
Urea	KCl	Absent	99.0	62.0	118.0	92.0	93.0
Urea	KCl	Present	128.0	73.0	97.5	125.0	106.0
S-Urea	KCl	Absent	67.0	141.0	49.0	133.0	98.0
Urea	SKCl	Absent	130.0	94.5	63.5	81.0	100.0
S-Urea	SKCl	Absent	112.0	70.5	87.0	112.0	95.0
S-Urea	SKCl	Present	64.5	60.0	44.0	87.5	64.0

* Uniform application of 168 kg N/ha and 140 kg K/ha from the sources.

Table 88. Phosphorus extracted by 0.03N NH_4F in 0.1N HCl from soil samples taken 5 months after fertilization in 1972 with various combinations of S-coated and non-coated CSP, urea, and KCl with and without plastic strip mulch

Treatment*			Replication				Mean
N source	K source	Plastic strip mulch	1	2	3	4	
			P, µg/g soil				
CSP (42 kg P/ha)							
Urea	KCl	Absent	116.0	75.0	59.5	122.0	93.0
Urea	KCl	Present	87.0	114.0	90.0	82.0	93.0
S-Urea	KCl	Absent	181.0	171.0	158.0	174.0	171.0
Urea	SKCl	Absent	135.0	164.0	185.0	171.0	164.0
S-Urea	SKCl	Absent	165.0	173.0	156.0	197.0	173.0
S-Urea	SKCl	Present	170.0	133.0	95.0	133.0	133.0
SCSP (42 kg P/ha)							
Urea	KCl	Absent	89.0	82.5	75.0	109.0	89.0
Urea	KCl	Present	86.0	41.0	69.5	52.0	62.0
S-Urea	KCl	Absent	126.0	58.5	79.0	31.4	74.0
Urea	SKCl	Absent	103.0	96.0	57.5	72.0	82.0
S-Urea	SKCl	Absent	57.0	62.0	110.0	81.0	77.0
S-Urea	SKCl	Present	95.0	94.0	73.5	113.0	94.0

* Uniform application of 168 kg N/ha and 140 kg K/ha from the sources.

Table 89. Phosphorus in corn ear-leaf tissue at 3 months of age from plots fertilized in 1972 with various combinations of S-coated and non-coated CSP, urea, and KCl with and without plastic strip mulch

Treatment*			Replication				Mean
N source	K source	Plastic strip mulch	1	2	3	4	
			P, %				
CSP (42 kg P/ha)							
Urea	KCl	Absent	0.313	0.306	0.318	0.306	0.311
Urea	KCl	Present	0.304	0.285	0.263	0.286	0.285
S-Urea	KCl	Absent	0.278	0.304	0.270	0.298	0.288
Urea	SKCl	Absent	0.303	0.354	0.298	0.295	0.313
S-Urea	SKCl	Absent	0.313	0.354	0.318	0.300	0.321
S-Urea	SKCl	Present	0.300	0.286	0.288	0.300	0.291
SCSP (42 kg P/ha)							
Urea	KCl	Absent	0.299	0.295	0.265	0.285	0.286
Urea	KCl	Present	0.304	0.306	0.273	0.278	0.290
S-Urea	KCl	Absent	0.295	0.289	0.295	0.318	0.299
Urea	SKCl	Absent	0.309	0.303	0.279	0.265	0.289
S-Urea	SKCl	Absent	0.373	0.334	0.341	0.286	0.334
S-Urea	SKCl	Present	0.273	0.310	0.333	0.293	0.302

* Uniform application of 168 kg N/ha and 140 kg K/ha from the sources.

Table 90. Aluminum in corn ear-leaf tissue at 3 months of age from plots fertilized in 1972 with various combinations of S-coated and non-coated CSP, urea, and KCl with and without plastic strip mulch

Treatment*			Replication				Mean
N source	K source	Plastic strip mulch	1	2	3	4	
			Al, ppm				
			CSP (42 kg P/ha)				
Urea	KCl	Absent	200	125	150	150	126
Urea	KCl	Present	175	200	125	100	150
S-Urea	KCl	Absent	225	125	225	175	188
Urea	SKCl	Absent	125	175	125	250	168
S-Urea	SKCl	Absent	125	150	175	125	144
S-Urea	SKCl	Present	125	125	125	150	131
			SCSP (42 kg P/ha)				
Urea	KCl	Absent	150	150	150	150	150
Urea	KCl	Present	225	225	150	150	188
S-Urea	KCl	Absent	125	150	150	175	150
Urea	SKCl	Absent	150	125	150	150	144
S-Urea	SKCl	Absent	100	125	150	125	125
S-Urea	SKCl	Present	150	125	150	150	144

* Uniform application of 168 kg N/ha and 140 kg K/ha from the sources.

Table 91. Iron in corn ear-leaf tissue at 3 months of age from plots fertilized in 1972 with various combinations of S-coated and non-coated CSP, urea, and KCl with and without plastic strip mulch

Treatment*			Replication				Mean
N source	K source	Plastic strip mulch	1	2	3	4	
			Fe, ppm				
		CSP (42 kg P/ha)					
Urea	KCl	Absent	190	170	175	178	178
Urea	KCl	Present	180	190	168	150	172
S-Urea	KCl	Absent	150	195	158	220	181
Urea	SKCl	Absent	158	200	188	195	185
S-Urea	SKCl	Absent	155	210	178	145	172
S-Urea	SKCl	Present	133	170	170	118	148
		SCSP (42 kg P/ha)					
Urea	KCl	Absent	158	160	160	165	161
Urea	KCl	Present	178	233	280	150	210
S-Urea	KCl	Absent	165	200	145	170	170
Urea	SKCl	Absent	203	198	138	193	183
S-Urea	SKCl	Absent	150	168	168	135	155
S-Urea	SKCl	Present	153	163	222	158	174

* Uniform application of 168 kg N/ha and 140 kg K/ha from the sources.

Table 92. Calcium in corn ear-leaf tissue at 3 months of age from plots fertilized in 1972 with various combinations of S-coated and non-coated CSP, urea, and KCl with and without plastic strip mulch

Treatment*			Replication				Mean
N source	K source	Plastic strip mulch	1	2	3	4	
			Ca, %				
		CSP (42 kg P/ha)					
Urea	KCl	Absent	0.383	0.333	0.350	0.375	0.360
Urea	KCl	Present	0.375	0.375	0.375	0.343	0.367
S-Urea	KCl	Absent	0.358	0.325	0.383	0.418	0.371
Urea	SKCl	Absent	0.383	0.368	0.393	0.375	0.380
S-Urea	SKCl	Absent	0.350	0.400	0.400	0.375	0.381
S-Urea	SKCl	Present	0.383	0.343	0.375	0.408	0.377
		SCSP (42 kg P/ha)					
Urea	KCl	Absent	0.368	0.375	0.433	0.325	0.375
Urea	KCl	Present	0.375	0.375	0.377	0.333	0.365
S-Urea	KCl	Absent	0.358	0.368	0.393	0.350	0.367
Urea	SKCl	Absent	0.375	0.325	0.408	0.358	0.367
S-Urea	SKCl	Absent	0.418	0.393	0.375	0.343	0.382
S-Urea	SKCl	Present	0.393	0.333	0.368	0.368	0.366

* Uniform application of 168 kg N/ha and 140 kg K/ha from the sources.

Table 93. Potassium in corn ear-leaf tissue at 3 months of age from plots fertilized in 1972 with various combinations of S-coated and non-coated CSP, urea, and KCl with and without plastic strip mulch

Treatment*			Replication				Mean
N source	K source	Plastic strip mulch	1	2	3	4	
			K, %				
		CSP (42 kg P/ha)					
Urea	KCl	Absent	1.88	1.98	1.98	1.93	1.94
Urea	KCl	Present	1.95	2.05	1.78	1.90	1.92
S-Urea	KCl	Absent	1.85	2.08	1.78	1.80	1.88
Urea	SKCl	Absent	1.90	2.03	2.01	1.88	1.96
S-Urea	SKCl	Absent	1.88	2.13	2.10	1.93	2.01
S-Urea	SKCl	Present	1.85	2.00	2.00	1.78	1.91
		SCSP (42 kg P/ha)					
Urea	KCl	Absent	1.85	1.93	1.78	1.98	1.89
Urea	KCl	Present	1.78	2.08	1.58	1.80	1.81
S-Urea	KCl	Absent	1.93	2.13	2.03	1.93	2.01
Urea	SKCl	Absent	2.01	1.81	1.78	1.68	1.82
S-Urea	SKCl	Absent	1.99	1.85	1.99	1.99	1.96
S-Urea	SKCl	Present	2.00	2.08	2.00	1.80	1.97

* Uniform application of 168 kg N/ha and 140 kg K/ha from the sources.

Table 94. Magnesium in corn ear-leaf tissue at 3 months of age from plots fertilized in 1972 with various combinations of S-coated and non-coated CSP, urea, and KCl with and without plastic strip mulch

Treatment*			Replication				Mean
N source	K source	Plastic strip mulch	1	2	3	4	
			Mg, %				
		CSP (42 kg P/ha)					
Urea	KCl	Absent	0.258	0.225	0.243	0.268	0.249
Urea	KCl	Present	0.275	0.210	0.253	0.260	0.250
S-Urea	KCl	Absent	0.263	0.213	0.275	0.290	0.260
Urea	SKCl	Absent	0.239	0.213	0.293	0.268	0.253
S-Urea	SKCl	Absent	0.240	0.193	0.280	0.273	0.247
S-Urea	SKCl	Present	0.238	0.245	0.220	0.255	0.240
		SCSP (42 kg P/ha)					
Urea	KCl	Absent	0.210	0.193	0.295	0.243	0.235
Urea	KCl	Present	0.240	0.215	0.283	0.243	0.245
S-Urea	KCl	Absent	0.210	0.230	0.243	0.248	0.233
Urea	SKCl	Absent	0.200	0.193	0.285	0.273	0.238
S-Urea	SKCl	Absent	0.265	0.220	0.258	0.255	0.250
S-Urea	SKCl	Present	0.240	0.208	0.250	0.293	0.248

* Uniform application of 168 kg N/ha and 140 kg K/ha from the sources.

Table 95. Manganese in corn ear-leaf tissue at 3 months of age from plots fertilized in 1972 with various combinations of S-coated and non-coated CSP, urea, and KCl with and without plastic strip mulch

Treatment*			Replication				Mean
N source	K source	Plastic strip mulch	1	2	3	4	
			Mn, ppm				
			CSP (42 kg P/ha)				
Urea	KCl	Absent	132	176	181	123	153
Urea	KCl	Present	132	243	139	113	157
S-Urea	KCl	Absent	106	172	154	78	128
Urea	SKCl	Absent	138	212	208	104	165
S-Urea	SKCl	Absent	100	171	139	106	129
S-Urea	SKCl	Present	73	140	147	111	118
			SCSP (42 kg P/ha)				
Urea	KCl	Absent	130	193	101	123	137
Urea	KCl	Present	111	136	150	95	123
S-Urea	KCl	Absent	92	166	132	97	122
Urea	SKCl	Absent	115	150	193	92	137
S-Urea	SKCl	Absent	106	161	135	100	126
S-Urea	SKCl	Present	135	161	174	104	144

* Uniform applications of 168 kg N/ha and 140 kg K/ha from the sources.

Table 96. Analysis of variance of corn yield response, soil and tissue P data of various combinations of coated and non-coated fertilizers with and without strip mulch, 1972

Source	df	Mean squares		
		Corn yield response		
		Kernel wt.	Ave. ear wt.	Yield
Blocks	3	1.1544	818.8968	1,708,228
Phosphorus (P)	1	0.0312	121.3942	5,674
Nitrogen (N)	1	0.1251	0.0000	239
P x N	1	0.0598	88.4738	151,694
Potassium (K)	1	0.0198	545.2453	1,059,528
P x K	1	0.0105	8.2301	179,345
N x K	1	0.0729	403.2758	10,750
P x N x K	1			
Mulch	1	0.0007	5,281.6785	2,047,678
P x M	1	0.0969	1,672.7716	303,746
N x M	1	0.2951	1,347.6819	745,450
P x K x M	1	0.0215	3,057.4890	5,569,493
Error	33	1.1281	2,524.5888	2,593,547
		Soil and tissue P responses		
		Soil P June	Soil P August	Tissue P Late-silking
Blocks		1,598.74*	643.46**	0.8648
Phosphorus (P)		5,253.12*	31,000.50**	0.0038
Nitrogen (N)		1,845.28	2,457.00*	0.0195
P x N		402.57	5,687.11**	2.6100*
Potassium (K)		608.13	2,408.18*	2.6136*
P x K		3,280.50	31.20	0.5200
N x K		995.70	1,702.36	2.0003*
P x N x K		855.95	3,152.18*	0.0003
Mulch		110.63	1,262.53	3.2805**
P x M		1,319.70	435.12	0.3645
N x M		1,158.01	4.50	0.6845
P x K x M		835.38	3,465.28*	0.5780
Error		1,026.77	523.83	0.3756

+ Mean squares must be multiplied by 10^{-3}.

* Significant at the 5% level.

** Significant at the 1% level.

Table 97. Correlation coefficients from study of various combinations of coated and non-coated fertilizers with and without strip mulch, 1972

Nutrient	Yield Z		Tissue P Late-silking stage	
	Linear r	Multiple r	Linear r	Multiple r
	Soil sampled in June 1972			
P	0.0406	0.1362		
	Soil sampled in August 1972			
P	-0.0006	-0.0020		
	Tissue at late-silking stage			
P	0.0027	0.0432		
Al	0.1866		-0.1135	0.1488
Fe	-0.0547		0.1312	0.1317
Ca	0.2539		0.1236	0.3510+
K	0.0661		0.4684*	0.5156
Mg	0.0857		-0.2859	0.3599
Mn	0.0259		0.1637	0.1637

+ Significant increase over that of linear r value due to inclusion of quadratic term in equation.

* Significant at the 5% level.

Table 98. Rainfall on field plots in 1973 from time of planting until corn harvest

Time after planting weeks	Rainfall per week cm
1	4.62
2	8.59
3	3.89
4	0.00
5	1.73
6	4.65
7	0.00
8	1.40
9	0.10
10	4.98
11	0.41
12	3.33
13	5.92
14	3.07
15	0.51
16	2.54
17	3.23
18	8.64
19	4.39
20	6.48
21	5.77
22	3.28
23	0.00

Table 99. Corn yields from 1973 Red Bay fsl plots with one- and two-year residual P as supplied by various rates of CSP and two SCSP materials

P treatment		Replication				Mean
1971	1972	1	2	3	4	
---- kg/ha ----		---------- Yield, kg/ha ----------				
		Check				
0	0	3300	3650	4650	2410	3500
0	0	4940	3320	3690	540	3110
		CSP (20.1% P)				
28	14	3880	5510	4870	6720	5250
28	0	4680	4070	5250	6680	5170
56	28	6920	6380	6030	5850	6290
56	0	5160	4320	4410	5220	4780
84	42	6440	6760	5960	6540	6430
84	0	5740	4710	3250	4710	4610
112	56	5370	6680	6220	5990	6070
112	0	4720	6080	5860	5170	5460
140	70	7270	7230	6500	6100	6780
140	0	4560	6040	5320	6690	4630
168	0	6300	6830	7410	5990	6630
168	0	5530	6780	5960	6100	6430
196	0	4730	6010	7170	6600	6130
196	0	5530	5550	6450	4680	5550
		SCSP (15.5% P)				
28	14	4990	4710	4680	3750	4530
28	0	6140	6550	4160	4170	5260
56	28	6600	5860	5740	6270	6120
56	0	5010	6940	4330	6190	5630
84	42	5790	6660	5800	5990	6070
84	0	4770	5010	6390	5960	5540
112	56	6220	6500	6270	6770	6440
112	0	4700	7560	5840	5160	5810
140	70	7080	6830	6720	6680	6830
140	0	5800	6230	4230	5930	5550

Table 99. Continued

P treatment 1971	P treatment 1972	Replication 1	Replication 2	Replication 3	Replication 4	Mean
kg/ha	kg/ha	Yield, kg/ha				
		SCSP (14.8% P)				
28	14	3880	5780	4830	4140	4660
28	0	2940	5350	3650	3740	3920
56	28	4870	5710	4710	5930	5310
56	0	2960	6730	4710	5300	4920
84	42	6990	5990	5440	6370	6200
84	0	5750	6890	5420	4240	5580
112	56	6000	6300	6000	5690	6000
112	0	5510	5400	5950	4680	5390
140	70	5750	7360	6740	6500	6630
140	0	6500	6590	6220	5460	6190

Table 100. Phosphorus extracted by 0.03N NH_4F in 0.1N HCl in 1973 from Red Bay fsl plots with one-and two-year residual P as supplied by various rates of CSP and two SCSP materials

P treatment 1971	P treatment 1972	Replication 1	2	3	4	Mean
kg/ha	kg/ha	P, µg/g soil				
		Check				
0	0	6.4	4.0	5.8	4.9	5.3
0	0	6.4	4.0	5.8	4.9	5.3
		CSP (20.1% P)				
28	14	17.2	13.7	9.7	14.2	13.7
28	0	5.3	4.1	8.2	5.9	5.9
56	28	14.4	12.6	16.4	14.3	14.4
56	0	7.6	5.9	7.6	7.8	7.2
84	42	13.8	12.6	14.1	22.0	15.6
84	0	13.8	18.6	13.4	9.3	13.8
112	56	19.1	22.7	26.7	16.0	18.6
112	0	15.3	13.7	11.9	9.0	12.5
140	70	23.2	19.1	19.3	27.7	22.3
140	0	7.9	9.5	8.0	14.3	9.9
168	0	23.0	16.2	24.4	21.7	21.3
168	0	12.1	12.0	13.6	11.1	12.2
196	0	27.5	12.4	32.9	18.6	22.9
196	0	27.5	12.4	32.9	18.6	22.9
		SCSP (15.5% P)				
28	14	9.7	6.8	7.7	5.5	6.1
28	0	6.9	9.6	4.5	4.2	6.3
56	28	9.9	10.2	7.6	17.6	11.3
56	0	4.9	8.5	10.9	10.3	8.7
84	42	10.6	10.1	14.3	8.2	10.8
84	0	9.6	9.3	17.5	12.1	12.1
112	56	13.5	18.3	28.9	21.7	20.6
112	0	11.0	16.2	12.3	16.4	14.0
140	70	19.4	18.2	28.3	12.9	19.7
140	0	15.6	33.4	25.1	16.3	22.6

Table 100. Continued

P treatment		Replication				Mean
1971	1972	1	2	3	4	
---- kg/ha ----		---------- P, µg/g soil ----------				
		SCSP (14.8% P)				
28	14	5.1	5.8	7.0	8.7	6.7
28	0	6.4	9.1	4.6	4.7	6.2
56	28	8.8	9.7	11.0	10.0	9.9
56	0	12.2	11.5	11.8	11.7	11.8
84	42	19.6	10.5	23.7	10.3	16.0
84	0	6.9	14.8	6.4	13.5	10.4
112	56	9.3	17.4	16.5	18.1	15.3
112	0	9.1	10.7	10.0	18.7	12.1
140	70	22.2	30.0	26.0	30.9	27.3
140	0	12.4	11.3	18.6	18.8	15.3

Table 101. Phosphorus in corn plant tissue at 3 months of age in 1973 with one-and two-year residual P from plots fertilized with several rates of CSP and two SCSP materials

P treatment		Replication				Mean
1971	1972	1	2	3	4	
kg/ha		P, %				
		Check				
0	0	.205	.225	.190	.163	.196
0	0	.235	.170	.179	.133	.179
		CSP (20.1% P)				
28	14	.243	.249	.203	.300	.249
28	0	.263	.205	.208	.288	.241
56	28	.348	.293	.193	.240	.269
56	0	.235	.260	.188	.233	.229
84	42	.283	.298	.245	.280	.274
84	0	.320	.243	.238	.205	.252
112	56	.265	.340	.270	.298	.293
112	0	.273	.273	.240	.253	.260
140	70	.338	.315	.290	.298	.310
140	0	.310	.313	.208	.245	.269
168	0	.338	.320	.263	.265	.297
168	0	.280	.310	.248	.273	.278
196	0	.238	.250	.315	.255	.265
196	0	.385	.273	.316	.218	.298
		SCSP (15.5% P)				
28	14	.270	.260	.195	.155	.220
28	0	.250	.280	.210	.183	.231
56	28	.278	.293	.245	.253	.267
56	0	.280	.270	.215	.210	.244
84	42	.260	.275	.300	.220	.264
84	0	.225	.278	.300	.203	.252
112	56	.308	.318	.253	.238	.279
112	0	.288	.293	.265	.218	.266
140	70	.310	.298	.278	.240	.282
140	0	.320	.275	.255	.253	.277

Table 101. Continued

P treatment		Replication				Mean
1971	1972	1	2	3	4	
---- kg/ha ----		---------- P, % ----------				
		SCSP (14.8% P)				
28	14	.195	.240	.233	.163	.208
28	0	.198	.240	.208	.193	.210
56	28	.285	.240	.250	.263	.260
56	0	.212	.293	.208	.263	.244
84	42	.300	.288	.240	.235	.266
84	0	.275	.263	.215	.175	.232
112	56	.298	.323	.273	.253	.287
112	0	.263	.263	.263	.228	.254
140	70	.308	.310	.310	.275	.301
140	0	.315	.248	.293	.273	.282

Table 102. Aluminum in corn plant tissue at 3 months of age in 1973 after one or two years' residual from plots fertilized with several rates of CSP and two SCSP materials

P treatment		Replication				Mean
1971	1972	1	2	3	4	
---- kg/ha ----		---------- Al, ppm ----------				
		Check				
0	0	125	125	100	100	113
0	0	100	175	133	125	133
		CSP (20.1% P)				
28	14	150	175	125	100	138
28	0	200	200	100	125	156
56	28	150	150	125	175	150
56	0	150	175	100	175	150
84	42	100	108	100	125	108
84	0	150	125	100	125	125
112	56	200	150	100	125	144
112	0	175	100	100	125	125
140	70	175	125	100	150	138
140	0	200	125	100	175	150
168	0	175	150	100	150	144
168	0	175	150	125	150	150
196	0	275	100	125	125	156
196	0	200	125	100	175	150
		SCSP (15.5% P)				
28	14	200	150	125	100	144
28	0	150	125	175	150	150
56	28	125	150	150	175	150
56	0	100	150	150	200	150
84	42	175	150	150	125	150
84	0	175	150	158	150	158
112	56	125	150	100	125	125
112	0	175	125	125	125	138
140	70	150	100	100	175	131
140	0	175	125	100	150	138

Table 102. Continued

P treatment 1971	P treatment 1972	Replication 1	2	3	4	Mean
kg/ha	kg/ha	Al, ppm				
		SCSP (14.8% P)				
28	14	175	125	100	150	138
28	0	175	100	125	125	131
56	28	175	100	150	125	138
56	0	200	200	150	100	163
84	42	150	125	100	125	125
84	0	125	100	100	125	113
112	56	108	100	75	150	108
112	0	175	125	100	125	131
140	70	125	125	75	125	113
140	0	125	150	100	150	131

Table 103. Iron in corn plant tissue at 3 months of age in 1973 after one and two years' residual from plots fertilized with several rates of CSP and two SCSP materials

P treatment		Replication				Mean
1971	1972	1	2	3	4	
---- kg/ha ----		---------- Fe, ppm ----------				
		Check				
0	0	188	120	120	118	119
0	0	115	125	113	115	117
		CSP (20.1% P)				
28	14	130	128	153	130	134
28	0	145	138	143	128	139
56	28	143	118	128	130	130
56	0	138	138	138	138	138
84	42	123	113	125	138	125
84	0	118	125	133	120	124
112	56	140	120	110	128	125
112	0	135	120	115	123	123
140	70	140	105	123	128	124
140	0	158	123	113	133	132
168	0	153	130	115	125	131
168	0	153	135	123	128	135
196	0	163	118	118	115	129
196	0	158	123	158	130	142
		SCSP (15.5% P)				
28	14	168	133	135	105	135
28	0	138	130	134	133	134
56	28	133	143	133	140	137
56	0	128	138	125	140	133
84	42	130	135	118	130	128
84	0	145	135	115	130	131
112	56	125	123	120	120	122
112	0	140	130	130	130	133
140	70	120	105	128	140	123
140	0	130	123	128	143	131

Table 103. Continued

P treatment 1971	P treatment 1972	Replication 1	Replication 2	Replication 3	Replication 4	Mean
kg/ha	kg/ha	Fe, ppm	Fe, ppm	Fe, ppm	Fe, ppm	Fe, ppm
		SCSP (14.8% P)				
28	14	118	130	115	125	122
28	0	110	110	120	128	117
56	28	128	130	130	130	130
56	0	120	125	138	118	125
84	42	110	120	110	130	118
84	0	120	105	118	120	116
112	56	125	128	113	128	124
112	0	125	135	113	130	126
140	70	125	125	113	120	121
140	0	123	130	115	133	125

Table 104. Analysis of variance of corn yield, soil and tissue P data of experiment 5, 1973

Source	df	Mean squares		
		Yield	Soil P March	Tissue P Late-silking+
Blocks	3	3,094,539**	27.3721	13.9176**
Rate (R)				
Linear	1	26,056,564**	2,023.6234**	48.1950**
Quadratic	1	843,780	4.8336	0.2916
Cubic	1	1,391,163	2.6460	0.7633
Quartic	1	516	0.0000	0.7547
Source	2	891,416	3.0586	1.1298
Source x Rate	8	708,536	36.3712*	0.6249
Error (a)	42	711,012	15.1094	1.3174
Fertilization (F)	1	13,717,180**	537.2101**	11.1554**
F x Rate	4	911,815	31.1909	0.8443
F x Source	2	971,302	101.6286**	1.0619
F x R x Source	8	591,540	41.1816*	0.1373
Error (b)	45	471,874	14.7322	0.4995

+ Mean squares must be multiplied by 10^{-3}.

* Significant at the 5% level.

** Significant at the 1% level.

Table 105. Correlation coefficients from residual P study (experiment 5), 1973

Nutrient	Yield		Tissue P	
			Late-silking stage	
	Linear r	Multiple r	Linear r	Multiple r
	Soil sampled in March 1973			
P	0.5065**	0.5872+		
	Tissue at late-silking stage			
P	0.6998**	0.7425+		
Al	-0.1465		0.0503	0.0854
Fe	-0.0264		0.1309	0.1324

+ Significant increase over that of linear r value due to inclusion of quadratic term in equation.

** Significant at the 1% level.

Table 106. Corn yields from 1973 Red Bay fsl plots as influenced by 126 kg residual P/ha supplied by various treatments

1971 Treatment (84 kg P/ha)		Replication				Mean
SCSP	Additive	1	2	3	4	
%		kg/ha				
CSP additive in 1971; 42 kg P/ha as CSP (20.1% P) in 1972						
0	100	6680	6710	5450	6250	6280
20	80	6170	4920	6400	5660	5790
40	60	6450	5640	7120	6430	6420
60	40	5950	5950	6370	7500	6440
80	20	7460	6890	11450	7470	8330
100	0	7970	5070	5780	8070	6730
OSP additive in 1971; 42 kg P/ha as SCSP (15.5% P) in 1972						
0	100	8170	6450	7480	6500	7160
20	80	6450	6910	5650	4990	6000
40	60	7350	7110	5320	6920	6680
60	40	6670	6340	7080	6400	6630
80	20	7350	5580	7620	6790	6830
100	0	6820	6400	6500	6630	6590

Table 107. Phosphorus in corn plant tissue at 3 months of age in 1973 as influenced by 126 kg residual P/ha supplied by various treatments

1971 Treatment 84 kg P/ha		Replication				Mean
SCSP	Additive	1	2	3	4	
------ % -------		---------- P, % ----------				
CSP additive in 1971; 42 kg P/ha as CSP (20.1% P) in 1972						
0	100	.288	.250	.315	.260	.278
20	80	.255	.233	.230	.228	.237
40	60	.268	.258	.300	.303	.282
60	40	.268	.320	.283	.275	.287
80	20	.275	.263	.280	.265	.271
100	0	.288	.240	.285	.280	.273
OSP additive in 1971; 42 kg P/ha as SCSP (15.5% P) in 1972						
0	100	.250	.265	.300	.270	.271
20	80	.250	.258	.235	.265	.252
40	60	.273	.275	.280	.290	.280
60	40	.293	.275	.283	.275	.282
80	20	.258	.258	.295	.273	.271
100	0	.260	.298	.260	.295	.278

Table 108. Aluminum in corn plant tissue at 3 months of age in 1973 taken from plots supplied with 126 kg residual P/ha supplied by various treatments

1971 Treatment 84 kg P/ha		Replication				Mean
SCSP	Additive	1	2	3	4	
------ % -------		---------- Al, ppm ----------				
CSP additive in 1971; 42 kg P/ha as CSP (20.1% P) in 1972						
0	100	150	150	125	125	138
20	80	133	125	150	125	133
40	60	100	175	150	125	138
60	40	150	175	150	125	150
80	20	125	200	150	125	150
100	0	125	150	142	150	142
OSP additive in 1971; 42 kg P/ha as SCSP (15.5% P) in 1972						
0	100	100	150	150	100	125
20	80	225	200	150	150	181
40	60	150	175	125	150	150
60	40	125	150	150	125	138
80	20	125	175	175	125	150
100	0	125	175	125	100	131

Table 109. Iron in corn plant tissue at 3 months of age in 1973 taken from plots supplied with 126 kg residual P/ha supplied by various treatments

1971 Treatment 84 kg P/ha		Replication				Mean
SCSP	Additive	1	2	3	4	
------ % -------		---------- Fe, ppm ----------				
CSP additive in 1971; 42 kg P/ha as CSP (20.1% P) in 1972						
0	100	135	143	145	125	137
20	80	118	125	148	125	129
40	60	113	140	128	133	129
60	40	110	160	133	133	134
80	20	130	145	128	128	133
100	0	128	153	138	128	137
OSP additive in 1971; 42 kg P/ha as SCSP (15.5% P) in 1972						
0	100	125	143	135	120	131
20	80	110	148	135	130	131
40	60	153	150	128	145	144
60	40	125	140	130	118	128
80	20	128	133	125	128	129
100	0	135	125	130	120	128

Table 110. Analysis of variance of corn yield, soil and tissue data of experiment 6, 1973

Source	df	Mean square	
		Yield	Tissue P at late silking+
Blocks	3	1,493,631	0.3722
Mixture			
Linear	1	2,596,290	0.8850
Quadratic	1	111,548	0.0466
Cubic	1	6,452,842*	1.6706*
Quartic	1	228,090	5.1975**
Quintic	1	2,338,375	0.3230
Source (S)	1	2,230	0.0120
Mixture x S	5	1,264,279	0.1364
Error	33	929,414	0.3407

+ Mean squares must be multiplied by 10^{-3}
* Significant at the 5% level
** Significant at the 1% level

Table 111. Correlation coefficients from residual P study (experiment 6), 1973

Nutrient	Yield		Tissue P	
			Late-silking stage	
	Linear r	Multiple r	Linear r	Multiple r
	Tissue at late-silking stage			
P	0.2244**	0.3989+		
Al	-0.0275		-0.0138	0.0413
Fe	-0.0845		0.0853	0.3009+

+ Significant increase over that of linear r value due to inclusion of quadratic term in equation.
** Significant at the 1% level.

Table 112. Soil- and tissue-P levels and corn yields of 1971, 1972, and 1973 as influenced by P applications at the first two years

P rate		Response		
1971	1972	1971	1972	1973
		Soil P, μg/g soil		
0	0	5.4	5.9	5.3
28	14	8.2	19.0	7.7
56	28	10.0	39.0	10.6
84	42	9.5	49.0	13.1
112	56	8.7	69.4	15.9
140	70	9.8	85.9	19.5
168	0	12.8	21.4	16.8
196	0	12.4	31.6	22.9
		Tissue P, %		
0	0	0.171	0.197	0.188
28	14	0.211	0.270	0.226
56	28	0.224	0.303	0.252
84	42	0.222	0.310	0.256
112	56	0.230	0.314	0.273
140	70	0.242	0.329	0.287
168	0	0.251	0.340	0.288
196	0	0.244	0.332	0.282

Table 112. Continued

P rate		Response		
1971	1972	1971	1972	1973
		Yield, kg/ha		
0	0	3,790	4,990	3,310
28	14	7,420	8,170	4,810
56	28	7,760	8,380	5,520
84	42	8,080	8,920	5,740
112	56	7,980	8,560	5,870
140	70	8,320	8,710	6,280
168	0	8,770	8,720	6,530
196	0	8,160	7,950	5,840

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BIOGRAPHICAL SKETCH

John J. Nicholaides, III, was born August 1, 1944, in Statesville, North Carolina. Shortly after his birth his family moved to Charlotte, North Carolina, where he attended public schools, graduating from Garinger High School in May 1962. The following autumn he enrolled as a freshman at Charlotte College, now the University of North Carolina at Charlotte. In September 1964, he transferred to North Carolina State University at Raleigh where he received the degree of Bachelor of Science, with Honors, from the Department of Soil Science. Immediately following graduation, he enrolled in the graduate program of the same department, receiving the degree of Master of Science in January 1969.

From February 1969, through August 1970, he served in the United States Peace Corps as a volunteer at the Instituto Nacional de Agricultura in Divisa, Panama where he conducted a soil survey of the institute, taught basic soils courses, and served as a soils consultant.

In September 1970, he enrolled as an NDEA Title IV Fellow in the Department of Soil Science at the University of Florida where he has remained until the present time, pursuing his work toward the degree of Doctor of Philosophy.

The author was married to the former Marjorie Gwynne Myers on January 29, 1967, and they have a daughter, Gwynne Elizabeth.

He is a member of the American Society of Agronomy and the Soil Science Society of America. He also is a member of Sigma Xi, Gamma Sigma Delta, Phi Sigma, Alpha Zeta, Phi Theta Kappa, and Sigma Tau Sigma honorary societies.

I certify that I have read this study and that in my opinion it conforms to acceptable standards of scholarly presentation and is fully adequate, in scope and quality, as a dissertation for the degree of Doctor of Philosophy.

John G. A. Fiskell, Chairman
Professor of Soils

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Lucian W. Zelazny
Assistant Professor of Soils

I certify that I have read this study and that in my opinion it conforms to acceptable standards of scholarly presentation and is fully adequate, in scope and quality, as a dissertation for the degree of Doctor of Philosophy.

David H. Hubbell
Associate Professor of Soils

I certify that I have read this study and that in my opinion it conforms to acceptable standards of scholarly presentation and is fully adequate, in scope and quality, as a dissertation for the degree of Doctor of Philosophy.

William G. Blue
Professor of Soils

I certify that I have read this study and that in my opinion it conforms to acceptable standards of scholarly presentation and is fully adequate, in scope and quality, as a dissertation for the degree of Doctor of Philosophy

Salvadore J. Locascio
Professor of Vegetable Crops

This dissertation was submitted to the Graduate Faculty of the College of Agriculture and to the Graduate Council, and was accepted as partial fulfillment of the requirements for the degree of Doctor of Philosophy.

December, 1973

asst Dean, College of Agriculture

Dean, Graduate School

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